AD-A260 815

(2)

DRIVE (Distribution and Repair in Variable Environments)

Design and Operation of the Ogden Prototype

Louis W. Miller, John B. Abell

RAND | PROJECT AIR FORCE

The research reported here was sponsored by the United States Air Force under Contract F49620-91-C-0003. Further information may be obtained from the Long Range Planning and Doctrine Division, Directorate of Plans, Hq USAF.

Library of Congress Cataloging in Publication Data

Miller, L. W. (Louis W.), 1935–
DRIVE (Distribution and Repair in Variable Environments) : design and operation of the Ogden prototype / Louis W. Miller, John B. Abell.
p. cm
"Prepared for the United States Air Force."
Includes bibliographical references.
"R-4158-AF."
ISBN 0-8330-1243-6
1. United States. Air Force—Inventory control—Computer programs. 2. United States. Air Force—Equipment—Maintenance and repair—Computer programs. 3. Airplanes, Military—United States—Maintenance and repair—Computer programs. 4. Ogden Air Logistics Center (U.S.)—Data processing. I. Abell, John B. II. United States. Air Force. III. Title.
UG1123.M56 1992
358.4'183'0288—dc20 92-13079
CIP

Published 1992 by RAND
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138

R-4158-AF

DRIVE (Distribution and Repair in Variable Environments)

Design and Operation of the Ogden Prototype

Louis W. Miller, John B. Abell

A Project AIR FORCE Report
prepared for the
United States Air Force

RAND

PREFACE

This report describes the design and operation of a mechanism that was developed and demonstrated in prototype form at the Ogden Air Logistics Center (ALC). Called DRIVE (Distribution and Repair in Variable Environments), it is the kernel of an improved approach to managing the component repair workload at Air Logistics Centers. Specifically, very current snapshots of the worldwide asset position, coupled with specified aircraft availability goals at bases and item characteristics drawn from standard Air Force Logistics Command (AFLC) data systems, are used by a computer-based algorithm to prioritize component repairs and allocate the assets to locations worldwide in a way that approximately maximizes the probability of achieving the availability goals. This approach contrasts sharply with the current component repair system, in which component repairs are a matter of negotiation at the ALC based on estimated repair requirements stated by the item manager (IM) and asset data that are six to nine months old at the time the repairs take place.

This work was part of a RAND project carried out in the Resource Management and System Acquisition Program of Project AIR FORCE entitled "Enhancing the Responsiveness of the Logistics System in the Face of Wartime and Peacetime Uncertainties," popularly known as the *Uncertainty Project.* The several publications of the Uncertainty Project are shown in the following list. The first of these provides an overview of the project. The last is a companion report to this one; it describes the current repair planning system, the logic and motivation for DRIVE, evaluations of its performance, the need for systematic reallocation of assets in the logistics system and DRIVE's utility for that purpose, the implementation and policy issues raised in its demonstration at Ogden in prototype form, and the future developmental directions needed to ensure its viability and effectiveness in the Air Force's logistics management system.

- Cohen, I. K., John B. Abell, and Thomas F. Lippiatt, *CLOUT (Coupling Logistics to Operations to Meet Uncertainty and the Threat): An Overview*, RAND, R-3979-AF, 1992.
- Crawford, Gordon B., *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, RAND, R-3318-AF, January 1988.

- Isaacson, Karen E., and Patricia Boren, *Dyna-METRIC Version 5: A Capability Assessment Model Including Constrained Repair and Management Adaptations*, RAND, R-3612-AF, August 1988.
- Tsai, Christopher L., *Dyna-SCORE: Dynamic Simulation of Constrained Repair*, RAND, R-3637-AF, July 1989.
- Abell, John B., et al., *DRIVE (Distribution and Repair in Variable Environments): Enhancing the Responsiveness of Depot Repair*, RAND, R-3888-AF, 1992.

This work was sponsored by Headquarters, U.S. Air Force (AF/LGX), and Headquarters, Air Force Logistics Command (AFLC/XP and AFLC/MM). It should be of interest to logistics managers and analysts throughout the Air Force logistics system and to logisticians in the other military departments. It is oriented toward those who have a particular interest in the operation and use of DRIVE and who wish to have a more intimate knowledge of its algorithms and file structures than described in R-3888-AF.

SUMMARY

A principal feature of the Air Force Logistics Command's (AFLC) current system for managing certain aspects of the repair of aircraft recoverable spares[1] is the negotiation of quarterly repair goals on an item-by-item basis before the start of each fiscal quarter. In execution, the negotiated quantities are regarded as targets, although they are often renegotiated as the quarter progresses (typically downward, due to shortages of repairable carcasses or repair parts). The negotiated repair quantities are strongly influenced by past histories of demands and repairs; however, the variability in demand for aircraft recoverable spare parts is often high, making it difficult to forecast component repair requirements over quarterly and longer planning horizons. Moreover, the longer the planning horizon over which the forecast is made, the more uncertain the forecast will be. Our uncertainty about resource demands suggests the need for repair management to be flexible and adaptive, to adjust the planned repair mix frequently if need be, and to be sensitive to the evolving worldwide asset position.

Another key feature of the current system of component repair management is that it determines repair requirements based on asset data that are six to nine months old at the time the repairs take place, making the system (a) somewhat insensitive to the current, most urgent needs of the combat force, and (b) vulnerable to demand and pipeline variability that perturb the asset position. In its determination of repair requirements, the current system does not incorporate explicit consideration of aircraft availability goals; therefore, it is not well oriented toward combat readiness or maintaining an asset position well balanced for combat sustainability.[2]

DRIVE (Distribution and Repair in Variable Environments) was developed as an alternative approach to the current system for managing the repair of aircraft recoverable assets at depots. DRIVE is a mechanism that prioritizes component repairs and asset allocations across very short planning horizons. It also estimates quarterly repair requirements and supports management analysis of individual

---

[1]A *recoverable* part is one that is subject to repair when it fails, rather than being discarded or consumed in use as *consumable* parts are.

[2]An important exception to this orientation is the genuine priority given to MICAP (mission capability) requirements.

LRU families.[3] It was demonstrated at the Ogden Air Logistics Center using F-16A/B avionics components as a case study. The demonstration led to the adoption of DRIVE's approach as an AFLC standard system. The production version of the system is being implemented at the time of this writing.

Rather than prescribing repair quantities over a long horizon, DRIVE is run much more frequently (every two weeks in the Ogden demonstration) using a current snapshot of the worldwide asset position. These data are combined with user-specified scenario data (force beddown, flying hours, etc.), information from several standard AFLC data systems, and aircraft availability goals specified by mission/design-base combinations (e.g., F-16A/Bs at Moody AFB would have an availability goal). DRIVE produces prioritized lists of items to be repaired in the next two-week production period, along with suggested priorities for allocating serviceable assets to locations worldwide.

DRIVE does employ forecasts of demands, and it assumes that the need for LRU and SRU repairs is related to flying hours. The forecast horizons, however, are short, and because DRIVE is run frequently and pays attention to the current asset position, it is self-correcting. DRIVE considers two echelons of repair (depot and intermediate) and two levels of indenture (LRUs and SRUs). It is weapon system oriented in that it seeks to maximize a measure related to weapon system availability goals, subject to constraints on repair capacity and availability of repairable carcasses.

In setting priorities, DRIVE looks to the end of a planning horizon that is roughly the point in time when repair actions taken in the near future would have an effect on the bases. The length of a planning horizon reflects the age of the asset position data plus time to have a repairable carcass inducted into the shop, a nominal repair lead time, and a base-specific shipping time. (Altogether, this is roughly 20 to 30 days for items in the Ogden demonstration.) Each model/design-base is assigned an *availability goal*, specifying the percent of the aircraft that are to be missing none of the parts under the purview of DRIVE.

[3]We define an LRU family as an LRU and all of its recoverable SRUs. An LRU is a line-replaceable unit, a component that typically is removed from an aircraft when a discrepancy is suspected. An SRU is a shop-replaceable unit that is a subcomponent of an LRU. SRUs are typically removed and replaced during intermediate-level repairs of LRUs.

DRIVE's repair prioritization algorithm seeks to maximize the probability that all bases will meet their availability goals, subject to the depot's repair capacity.[4] It arrives at priorities by applying step-by-step marginal analysis. At each step, it evaluates the improvement in the objective function that would be achieved for each possible repair and allocation action (i.e., which base is to receive the repaired item). Associated with every action, there is a "cost" in terms of standard repair hours. DRIVE chooses the action with the largest improvement in the objective function (which for technical reasons is based on logarithms of probabilities) divided by the standard hour cost. The order in which repair and distribution actions are selected by the marginal analysis determines the priorities. Because of the way that repair hours are included in the computation, the sequence of priorities is efficient in that if the priority list is cut off at any point, the set of repair and allocation actions defined thereby would achieve approximately the highest possible probability of meeting the availability goals at all the bases for the total amount of standard repair hours expended.

DRIVE uses the forecasts of bases' demands for assets during the planning horizon to specify parameters of probability distributions that are the basis of the computations in the prioritization algorithm. The prioritization calculations are complicated by several factors. The typical base has the capability to repair LRUs by replacing defective SRUs. Thus, when DRIVE considers the asset position at each base, it must have visibility of serviceable spares on hand and in transit to the base, and AWP shortages[5] in DIFM LRUs.[6] At each step of the marginal analysis, it evaluates several options including sending LRUs to bases, sending "packages" of SRUs that allow bases to repair their own AWP LRUs, and sending SRUs to bases to have on hand for future needs. In evaluating these options, DRIVE assumes that bases cannibalize, to the extent needed, both LRUs across aircraft and SRUs across LRUs. Thus with any given number of LRUs missing from aircraft and number of SRUs missing from LRUs, the "holes" are consolidated into the minimum possible number of aircraft

[4]Repair capacity is measured in standard hours. The standard hour measure is an engineered standard used throughout AFLC's depot maintenance activities for a wide variety of management and accounting purposes.

[5]AWP assets are awaiting parts. In DRIVE, only shortages of recoverable components are considered.

[6]DIFM assets are due in from maintenance, that is, they have been issued to base maintenance in repairable condition and have not yet been repaired and returned to supply in serviceable condition. One reason for DIFM status is, of course, lack of repair parts.

and LRUs. DRIVE also considers several ways for the depot to increase the probability that a base will achieve its availability goal. There may be serviceable items available in depot stock, there may be LRUs in the depot- or base-repair process needing SRUs, or unserviceable LRUs can be inducted into the repair shop. DRIVE can specify the repair of SRUs needed to complete LRU repairs, and it also provides for a sufficient number of SRUs to be made available so that there is a high probability that repairs of newly inducted LRUs will not be delayed for lack of serviceable SRUs.

While the previous paragraphs outline the essential features of DRIVE's priority-setting process, going from initial data to final priority lists is more complicated, and we have divided the process into the following five steps:

1. Assemble data from Air Force standard data systems and other sources.
2. Accept users' inputs and choices of options, perform preliminary calculations, and reorganize and distill information from the first step.
3. Generate prioritized sequences of repair actions and recommendations for distribution.
4. Adjust results from step 3 for shop capacity.
5. Construct human-usable priority lists.

The first step is carried out with the *preprocessor*, a computer program written by personnel at the Ogden Air Logistics Center (ALC). The preprocessor utilizes data extracted from half a dozen AFLC standard systems, plus specially maintained files, to produce an output file containing information about bases and about the LRUs and SRUs whose repairs are prioritized by DRIVE.

The second step serves as a bridge between the output of the preprocessor and the priority calculations. Its roles are to accept users' inputs, do some preliminary calculations, and organize information needed by subsequent steps in a compact form. The preliminary calculations relate to demand rates and deriving allowable numbers of LRUs missing from aircraft at bases from the original availability goals. Step 2 also invokes some approximations needed to agree with assumptions made by the priority calculation. One assumption is that each LRU has its own unique set of SRUs. The most important adjustment made in step 2 is mitigating between needs for primary operating stock (POS) and maintaining full war readiness spares kits

(WRSK), which are possessed by some units whose wartime missions call for deployment without capability for repairing LRUs. For such bases, DRIVE increases expected demands during the planning horizon by assuming that aircraft at those bases will fly at wartime rates for 30 days at the end of their horizons. This is DRIVE's way of providing spares for wartime sustainability and at the same time being "fair" to bases with peacetime training programs that are not authorized WRSK.

Most of DRIVE's mathematics is embodied in the third step, which calculates prioritized sequences of repair actions and priorities for allocating items from the depot to bases. The priority calculation of step 3 does not account for repair capacity constraints. Instead, the priority lists are deliberately made generously long. The lists are then truncated in step 4 with an interactive procedure that we call *line drawing*, a term suggested by the image of drawing a line across a globally optimized priority list. The line-drawing program also estimates the number of SRUs that should be made available for repairing LRUs in the production period beyond the one of immediate concern. This supports our notion of *proactive SRU repair*, which is the idea that LRU repairs are likely to be accomplished more quickly and efficiently if appropriate stocks of SRUs are on hand. Following the line-drawing operation of step 4, DRIVE prepares priority lists for the repair shops and for use by item managers in allocating assets.

In addition to these five steps, we have also constructed an interactive computer program called the DRIVE Decision Support Program (DDSP) that can replay the sequence of decisions that the prioritization algorithm has made. It was originally intended as a pedagogical device to aid in explaining how DRIVE works, but we have found it to be a very useful diagnostic tool in helping us understand the particular situation and problems concerning any LRU family. One reason the DDSP is so useful is that the DRIVE database brings together a wealth of information in ways that no other data system does, and the DDSP graphically displays statistics derived from those data. The DDSP's displays help humans synthesize the voluminous quantities of data that are pertinent to the performance of the system with respect to any particular LRU family.

A final topic addressed in this report is quarterly repair planning. Although DRIVE is intended to replace the current system of working toward negotiated quarterly goals, we still need to estimate quarterly repair quantities for manpower planning, laying in consumable repair parts, and make similar resource-allocation decisions. We considered a number of ways to do this and developed a simulation model to

evaluate various methods. The method found most satisfactory is to use DRIVE as though the depot were going to accomplish a quarter's worth of repairs in the last production period of the quarter. The precision of any quarterly planning method, however, is limited by the underlying variability of the demand processes for spare parts.

ACKNOWLEDGMENTS

The authors are indebted to many persons at RAND and in the Air Force who helped in one way or another with this development and demonstration. At RAND, Karen Isaacson contributed her programming skills to the software that produces the DRIVE input database; the late Dr. Gordon B. Crawford originally formulated the objective function used in DRIVE.

Dr. Craig C. Sherbrooke resolved important modeling issues in DRIVE's early formulation and wrote the original computer code for the DRIVE algorithm. He was also involved in a RAND effort in 1968 to implement a repair prioritization algorithm at Ogden, an effort that never reached fruition.

At Ogden, Sheldon Bowe programmed the original preprocessor that translated the many files derived from standard AFLC data systems to the DRIVE input database.

At Headquarters, AFLC, Richard Moore provided many helpful and competent evaluations, suggestions, and improvements to the DRIVE software.

CONTENTS

FIGURES

TABLES

GLOSSARY

AFLC	Air Force Logistics Command.
AIS	Avionics intermediate shop. The maintenance shop that repairs avionics LRUs. Shops with this name are located at bases as well as the depot.
ALC	Air Logistics Center. One of five subcommands of AFLC responsible for logistics support of Air Force systems.
AWP	Awaiting parts.
BLSS	Base-level self-sufficiency stock. Spares that are authorized for units that are expected to fight in place. In the context of this research, BLSS is authorized for main operating bases.
CONUS	Continental United States.
CSIS	Central Secondary Item Stratification.
D028	AFLC's central system for allocating stock levels for recoverable spares to the depot and bases.
D035	AFLC's Stock Control and Distribution System.
D035C	A subsystem of D035, formerly denoted D143, and that performs the same functions as D143 did.
D041	AFLC's Recoverable Consumption Item requirements System, the system for computing requirements for recoverable spares and depot-level repair.
D073	AFLC's system for component repair workloading.
D143	AFLC's system that formerly provided central visibility of the worldwide asset position for recoverable assets. It operated with data from the Air Force Recoverable Asset Management System.
D143H	The subsystem of D143 that captured asset positions worldwide.
D143K	The subsystem of D143 that captured assets in transit to or from bases.

D165	The Mission Capability Requisition Status Reporting System.
D165A	The Aerospace Vehicle and Selected Items of Equipment Mission Capable Status Reporting System.
DDSP	DRIVE Decision Support Program.
DIFM	Due in from maintenance.
DMSC	Depot maintenance support center. A storeroom near the shop.
Dyna-METRIC	Dynamic Multi-Echelon Technique for Recoverable Item Control. RAND has developed a series of capability assessment models to support policy analytic studies of the logistics system. Dyna-METRIC Version 4, an analytic model, is incorporated in AFLC's Weapon System Management Information System (WSMIS). Version 5, a simulation model, was used in this research. Version 6, an advanced, hybrid analytic-simulation model, the latest version of the Dyna-METRIC series, extends Version 5 to incorporate the indenture relationships among LRUs and SRUs, and adds more explicit representation of management adaptations.
Dyna-SCORE	Dynamic Simulation of Constrained Repair. A discrete-event, Monte Carlo simulation model of repair shops similar in repair process to the Avionics Intermediate Shop. Dyna-SCORE was developed to explore the payoffs of certain management adaptations in repair activities.
FAP	Fraction application percentage. The fraction of end items of a particular kind that contains a given type of LRU.
Force beddown	The posture of the combat force in terms of numbers of aircraft of each type at each location. The force beddown could also be specified by aircraft serial number.
IM	Item manager.
INU	Inertial navigation unit.

LPRF	Low-power radio frequency unit.
LRU	Line-replaceable unit. Components that are removed from aircraft when a discrepancy is suspected. In the indentured relationships among component parts of an aircraft, for example, they are typically thought of as component parts of subsystems.
LSRU	The name given to the computer program that embodies DRIVE's priority-setting logic as described in Section 2 of this report. It is a contraction of LRU and SRU.
MIC	Maintenance inventory center. Former name for DMSC.
MICAP	Mission capability. A term used to describe a condition such that an aircraft is not mission-capable for lack of a component part. The requisition in the supply system for that component part is called a MICAP requisition.
MISTR	Management of Items Subject to Repair. The current system that DRIVE is intended to replace. Quantities of items to be repaired during a quarter are negotiated and are taken as goals for execution.
MRIU	Missile release interface unit.
NFMC	Not fully mission-capable. The status of an aircraft that is flyable, but whose capability to perform its assigned mission is in some sense degraded, constrained, or inhibited.
NMCS	Nonmission-capable for supply.
NRTS	Not repairable this station. The status of a recoverable asset that cannot be repaired at intermediate level and must be returned to the depot for repair.
NSN	National stock number.
OIMDR	Organizational and intermediate maintenance demand rate.

PAA	Primary authorized aircraft. The number of aircraft allocated to a unit to carry out its assigned mission.
PACAF	Pacific Air Forces.
PMS	Production management specialist.
POS	Primary operating stock (formerly peacetime operating stock). Spare parts authorized to bases to support peacetime operations but which may also be used in wartime.
QPA	Quantity per application. The number of copies of an LRU in an end item. Also applies to SRUs in LRUs.
SBSS	Standard Base Supply System.
SRAN	Supply reporting activity number. An account number assigned to a base's accountable supply officer.
SRU	Shop-replaceable unit. A component of an LRU which is typically removed and replaced during intermediate-level repair.
USAFE	United States Air Forces Europe.
VTMR	Variance-to-mean ratio. The unbiased estimator of the variance divided by the mean of a stochastic process.
WRSK	War readiness spares kit. A set of spare parts that is authorized to a unit to help support its combat operations during the early days of wartime.
WSMIS	Weapon System Management Information System.
TRADES	Theater Repair and Distribution Execution System. A version of DRIVE used in regional repair centers.
X21 Report	A report of component repair requirements produced by AFLC's D073 system.

1. INTRODUCTION[1]

In its Uncertainty Project, RAND quantified the levels of variability in demand for aircraft recoverable spare parts observed during peacetime.[2] High variability makes forecasting requirements for serviceable assets to support the combat force more difficult, and the forecasts are vulnerable to the vagaries of repairable generations and the stochastic nature of the evolution of the asset position as time passes. The longer the planning horizon over which the forecast is made, the more difficult the forecasting problem becomes. Moreover, the difficulty of forecasting over long planning horizons will probably be compounded in wartime by system disruptions, resource losses, and the inevitable surprises the enemy is likely to create in the highly uncertain combat scenario.

As a matter of policy, Air Force units with deployment tasking are authorized war readiness spares kits (WRSKs), the contents of which are computed with the goal of having no more than a specified number of aircraft unavailable for lack of parts after 30 days of operation at wartime activity levels. This policy implicitly tries to avoid excessive dependence on replenishment during the early days of a combat contingency, a policy apparently rooted in the belief that transportation will be scarce during such periods. Given this policy, it is important not only to maintain high readiness in peacetime, but also to maintain an asset position well balanced for combat sustainability.

The current depot repair management system is not sensitive to the evolving asset position, nor does it incorporate explicit consideration of aircraft availability goals in repairing or allocating assets. During the fiscal quarter in which component repairs occur, the asset data underlying the estimation of repair requirements for that quarter are six to nine months old. The repair goals toward which the depot maintenance activity works are negotiated internally between functional entities within the Air Logistics Center (ALC). The goals are frequently adjusted during the quarter, typically downward, usually due to shortages of repairable carcasses or repair parts, owing to the

[1]The discussion in this section draws heavily from Abell, John B., et al., *DRIVE (Distribution and Repair in Variable Environments): Enhancing the Responsiveness of Depot Repair*, RAND, R-3888-AF, 1992.

[2]See Crawford, Gordon B., *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, RAND, R-3318-AF, January 1988.

failure of the current system to take explicit account of uncertainty in its repair-requirements determination process.

DRIVE was developed as an alternative to the current system and takes a very different approach to the problem. It uses a current snapshot of the asset position (literally only a couple of days old at the time the algorithm is run), coupled with aircraft availability goals specified by mission/design-base combination, e.g., F-16s at Moody Air Force Base (AFB) would have an availability goal. User-specified scenario data (goals, force beddown, flying hours, etc.) are combined with data elements from several standard Air Force Logistics Command (AFLC) data systems to support DRIVE's decisionmaking about prioritization of repairs within repair resources (e.g., automated test stands) and the allocation of serviceable assets to locations worldwide.

DRIVE produces two kinds of priority lists: a repair list for use by shop chiefs, schedulers, and others, and an allocation list for use by the item managers (IMs) in allocating assets to users. Actions are sequenced on the list in decreasing order of a numerical function reflecting both their contributions to the probability of meeting all the availability goals and their repair costs. Thus, no matter where one stops on the list, for that total repair cost (specified to DRIVE in standard repair hours, although other costs could be used), the probability of meeting all the availability goals will be approximately maximized; conversely, for a specified probability of meeting all the availability goals, DRIVE's sequenced repair list provides an approximately least-cost mix of component repairs to achieve it.

In its determination of the sequenced repair and distribution lists, DRIVE ignores base and depot stock levels and requisitions from the bases and focuses on the availability goals and the current asset position at each location. This is inconsistent with the requisitioning system currently in use in the Air Force. The inconsistency raises several important policy and implementation issues that suggest the need to evaluate an alternative approach in which DRIVE would allocate stock levels and prioritize asset allocations against requisitions in the system. Such an approach would resolve those issues and ease the implementation of a production version of DRIVE.

The move to a system whose objective function is oriented toward aircraft availability will be a cultural shock to the Air Force logistics system. It implies less emphasis on traditional measures of system performance such as MICAPs (parts shortages affecting mission capability) and AWPs (numbers of components awaiting repair parts). Traditional measures of performance will need to be subordinated to

aircraft availability. This change in emphasis will have important implications for logistics managers throughout the system.

The prototype of DRIVE was demonstrated at the Ogden Air Logistics Center. It was used to prioritize the repair and allocation of F-16 avionics LRUs and SRUs.[3] The demonstration was successful in the sense that it showed that such an approach was not only feasible but also that it could be expected to yield substantial improvement in peacetime readiness and wartime sustainability without additional costs. The demonstration was also helpful in identifying policy and implementation issues that will need to be resolved before implementation of a production version of the system.

Figure 1.1 reflects the results of some quantitative evaluations of DRIVE.[4] The three bars reflect F-16A/B aircraft availability on day 30 of a nominal wartime scenario in which shortages of the components being prioritized by the DRIVE prototype cause aircraft to be unavailable. In the first case, DRIVE is not used; the depot operates with its current repair-planning system. In the second case, DRIVE is used only to allocate the serviceable assets emerging from repair. The third case reflects full compliance with DRIVE's suggested asset repairs and allocations. The result is that roughly an additional one-fifth of the possessed aircraft are available on day 30, a dramatic improvement over the current system.

Our conclusions from the Ogden demonstration were that AFLC and the Air Staff should proceed with resolution of the issues that are troublesome to full implementation of DRIVE and develop a production version of the system. Since the Ogden demonstration, several events have occurred that influence the shaping of a desired future course in spares and repair management policy for the Air Force. An adaptation of DRIVE called TRADES (Theater Repair and Distribution Execution System) has been successfully demonstrated for use in

[3]LRUs are line-replaceable units, components usually removed from aircraft when suspected of being defective. The LRU is typically sent to an intermediate-level repair facility for fault diagnosis and repair. If it is beyond intermediate repair capability, it is declared to be NRTS (not repairable this station) and returned to the depot level for repair. An SRU is a shop-replaceable unit such as a circuit card or other subassembly of the LRU. LRUs are often repaired by removing and replacing one or more SRUs. In the Air Force, avionics SRUs are typically sent back to the depot for repair.

[4]These were done using Dyna-METRIC (Dynamic Multi-Echelon Technique for Recoverable Item Control), RAND's capability assessment model. They reflect the results of one fiscal quarter of simulated operation under the conditions described. Each case represents the same repair capacity. A detailed discussion can be found in Abell, John B., et al., *DRIVE*, R-3888-AF.

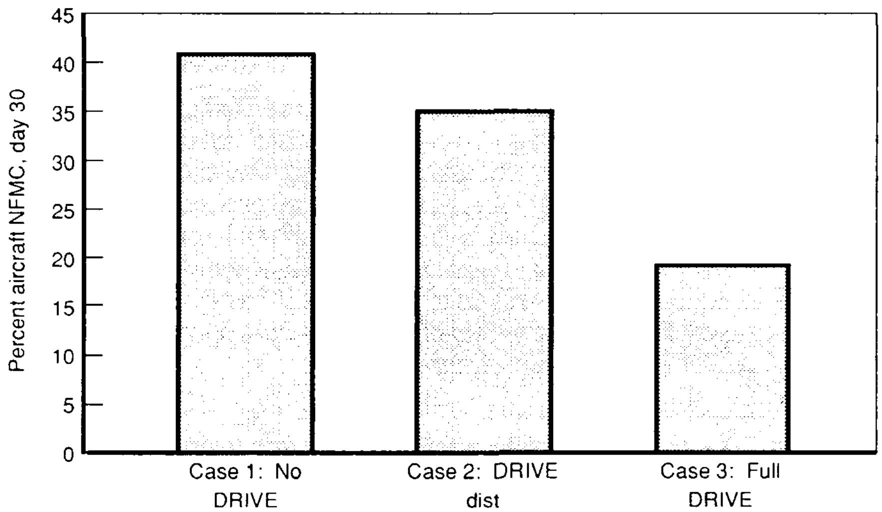

Figure 1.1—Payoffs of DRIVE's Repair and Distribution

managing repair and asset allocation at subdepot echelons of the system. It is intended for extension to other locations and raises the issue of integrated decisionmaking across echelons so that duplicative and inconsistent asset allocation decisions are avoided. At the time of this writing, additional research is being undertaken to develop and demonstrate an advanced multi-echelon spares and repair management system for the Air Force that will satisfy the need for multi-echelon integration. It is intended to be a requisition-based system that will operate with a shared database whose source data will include asset position snapshots from the standard base supply system (SBSS). This change in orientation from the DRIVE prototype will resolve several of the implementation issues raised in the prototype demonstration.

The most compelling single conclusion of the work described here and in R-3888-AF is that a DRIVE-like mechanism that prioritizes repairs and allocates serviceable assets using current data and specified aircraft availability goals, especially if coupled with responsive distribution and transportation systems that enable planning horizons to be much shorter than they are in the current system, can enable the depot component repair system to make a very substantial contribution to aircraft availability in peacetime and wartime. In this report, we discuss the design and operation of the DRIVE prototype, the deci-

sions we made in its design, its assumptions, its underlying logic, and its design as a decision support system.

Because the overall problem of determining repair and distribution priorities is fairly complex, the Ogden prototype is implemented as a five-step process. Dividing up the system in this way eased the management of the project, permitted the development of software on personal computers, and facilitated the participation of more than one person in the programming. Moreover, the availability of data files created between steps expedited debugging and enhanced our ability to analyze data. The five steps in the prioritization process are:

1. Assemble data from Air Force standard data systems and other sources.
2. Accept user's inputs and choices of options, perform preliminary calculations, and reorganize and compact information from the first step.
3. Generate prioritized sequences of repair actions and recommendations for distribution.
4. Adjust results from step 3 for shop capacity.
5. Construct human-usable priority lists.

Since most of DRIVE's mathematical computations and prioritization logic are incorporated into the third step, the details of step 3 are addressed next in Section 2. Section 3 discusses the second step, which serves as a bridge between the "real data" from step 1 and the somewhat idealized model upon which step 3 is based. The computer programming to implement the first step was accomplished by personnel at the Ogden ALC working from RAND's specification of the content and form of the desired output. The particular items of data produced in step 1 are also enumerated in Section 3.

Taking account of available shop capacity and balancing workload across repair resources are done as a fourth step after a (long) list of priorities is calculated. These functions were not integrated with the prioritization logic because we wished to limit the complexity of the priority calculations, and because we judged that there should be a high degree of human-computer interaction in working out the final production plan. Section 4 describes the "line-drawing" process of step 4 and the actual priority lists produced in step 5. Section 5 discusses an interactive program called the DRIVE Decision Support Program (DDSP) that allows one to observe the prioritization process. We have found the DDSP to be a worthwhile aid to understanding DRIVE and the source of valuable insights into problems with specific

LRUs. The diagnostic power of the DDSP derives from its graphical displays of large amounts of data about LRUs and their SRUs.

Although DRIVE is intended to be used frequently to make decisions over relatively short planning horizons there is need to take a longer view. Toward this end, we discuss in Section 6 some extensions to DRIVE to assist in quarterly repair planning.

In a companion report,[5] we describe the current depot component repair planning system in greater detail, as well as DRIVE's motivation and underlying logic, its expected performance in contrast to the current system, the payoff of systematic reallocation of assets in the logistics system, the policy and implementation issues raised by DRIVE in its demonstration at Ogden in prototype form, and future developmental directions that need to be taken to enhance its viability in the Air Force logistics system. The companion report is important to logistics policymakers, managers, and analysts throughout the system as well as to logisticians in the other services.

---

[5]Abell, John B., et al., *DRIVE*.

2. DRIVE'S MODEL FOR SETTING PRIORITIES

This section describes DRIVE's underlying model and logic for setting priorities as embodied in the third of the five steps listed in Section 1. The mathematics in step 3 assumes a somewhat simplified view of the world (for example, all aircraft at a base are configured in the same way; SRUs are unique to their parent LRUs). The approximations necessary to invoke the simplifications are applied in step 2, which is the topic of Section 3.

OVERVIEW OF THE SECTION

DRIVE employs a greedy, marginal-analytic algorithm[1] that indicates a sequence of actions to be taken at the depot. The objective function, however, is concerned with aircraft availability at bases. Thus, evaluating the objective function depends strongly on how bases are modeled. The ensuing explanation deals first with the objective function and DRIVE's model of base operations, followed by a description of how the depot is modeled. Then we discuss DRIVE's optimization algorithm, and we conclude with a description of the computational scheme that puts it all together. The many assumptions made by DRIVE's priority calculations are stated at appropriate points as the discussion progresses.

DRIVE'S OBJECTIVE FUNCTION

DRIVE seeks to maximize the probability that all bases will meet specified goals for aircraft availability at the end of a planning horizon.[2] The following paragraphs elaborate on what this means.

Aircraft Availability Goals

Aircraft availability refers to the number of aircraft at a base that are missing none of the parts under the purview of DRIVE. Each base

[1]This means that the solution is developed in a series of steps, where at each step a choice is made based on ratios of "benefit" to "cost" and, once a choice is made, it is not reversed in subsequent steps.

[2]In Section 1, we stated that DRIVE operates on goals for combinations of mission/designs and bases. We shall, however, distinguish only among bases in this report.

has an availability goal specifying the percent of its aircraft that are to be complete. The bases' goals are inputs to step 2.

Planning Horizons

Planning horizons are based on the idea that if the depot decides to repair an item in the near future, it will take some time to get the item into the repair facility, fix it, and have it delivered to a base. The end of the planning horizon marks the time when the combat forces will gain the benefit of an action taken in the near future. Planning horizons are allowed to vary among the bases owing to differences in shipping times to different parts of the world.

DRIVE's notion of a planning horizon is distinct from that of a production period, which is the interval over which the repairs being planned are to take place. Planning horizons, however, should be longer than production periods.[3]

Probabilities

Over a base's planning horizon, items may fail and be removed from aircraft. DRIVE is concerned only with whether or not the base has enough serviceable spare parts to repair or replace the failed items; it assumes that if the parts are available at the base by the end of the base's horizon, the repairs will be made. DRIVE has built-in assumptions about the stochastic nature of item failures (described later). Given data about a base's current assets, a specification of the items that the base will receive during the horizon (which is what DRIVE is responsible for planning), and the probability distributions describing the failures of items during the horizon, DRIVE calculates the probability that the base will meet its availability goal at the end of its horizon. Assuming independence among bases, the probability that all bases meet their goals is the product of the probabilities that the individual bases meet their goals.

DRIVE'S MODEL OF BASES

DRIVE performs probability calculations as part of its optimization procedure, and the calculations depend on how bases are modeled. The following paragraphs describe how DRIVE views bases and the

[3]At Ogden, DRIVE is run on alternate Tuesdays to make plans covering the two-week production period that begins on the following Monday, and planning horizons average around 26 days.

implications for probability computations. A mathematical description of the probability calculation is given later.

Cannibalization of LRUs and Further Decomposition of the Objective

A critical assumption is that the bases practice cannibalization whenever possible. This means that if LRUs are missing from aircraft at a base for lack of spares, good LRUs are shuffled between airplanes so that the maximum number of aircraft at a base are whole. Since the aircraft availability goal for a base implies the allowable number of aircraft missing LRUs, the cannibalization assumption allows the goal to be translated into goals for individual LRUs. For example, if a base's goal is that no more than five aircraft should be missing parts, then it is sufficient that no type of LRU should be responsible for more than five airplanes down.[4] This means that the probability that a base meets its goal is the product of probabilities that all the individual LRUs at the base meet their goals. Hence, the overall objective function is a double product of probabilities over bases and LRU types, assuming independence among LRUs and among bases.

The probability that a particular type of LRU is not responsible for a base failing to meet its goal is the probability that the number of LRUs that are removed from aircraft during the horizon is no more than the base's current stock of spares, plus LRUs that the base gains during the horizon, plus the allowable number of LRUs missing from aircraft (which we refer to as *holes*). If there happen to be holes for the LRU in question at the beginning of the horizon, the base is regarded as having negative stock.

Figure 2.1 illustrates the way in which DRIVE relates LRU asset positions, planning horizons, and goals. The diagram is a hypothetical plot of the asset position of one LRU at a base as a function of time. Positive points on the asset position scale represent the number of spare (i.e., not installed in aircraft) LRUs in stock at the base. Negative values indicate LRUs missing from aircraft. The origin of the time scale is the time at which the asset position was reported prior to running DRIVE (about two days), and the right-hand end marks the end of the planning horizon.

[4]The relationship between missing LRUs and aircraft down is slightly complicated when there are multiple copies of an LRU in the airplanes. If there are 3 copies, then, under the cannibalization assumption, 1, 2, or 3 of this type of LRU missing from aircraft results in one airplane not operational due to shortages of the LRU.

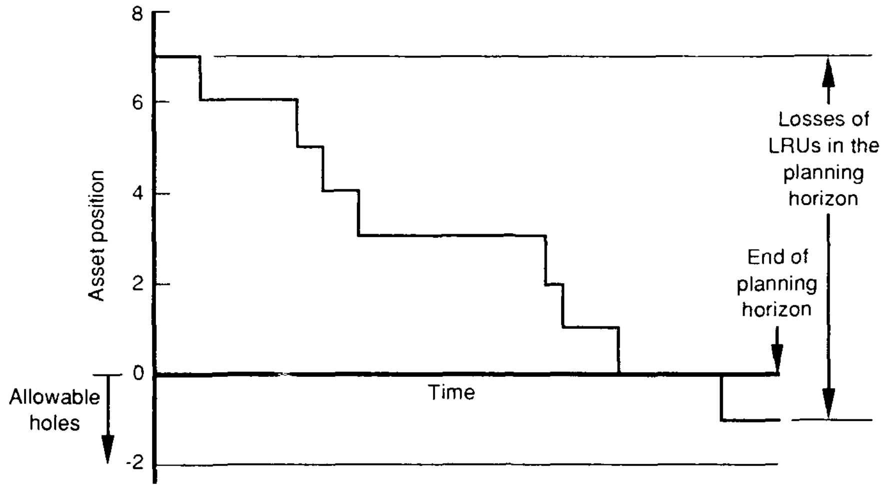

Figure 2.1—DRIVE's View of Asset Positions and Planning Horizons

The cannibalization assumption has two implications. First, a base would not have airplanes missing a type of LRU and also show that LRU to be in a positive asset position because DRIVE assumes that bases would fill all the LRU holes in airplanes with whatever stock is available. (Either all the holes for an LRU get filled, or all the stock of that LRU gets used up.) As already mentioned, the second implication is that the allowable number of LRUs missing from aircraft are directly implied by a base's availability goal, number of aircraft, and number of copies of the LRU on an airplane. The horizontal line at an asset position of –2 in Figure 2.1 indicates the allowable number of LRUs of this type that can be missing from airplanes at this base.

The irregular "staircase" in Figure 2.1 represents a possible realization of losses of an LRU at a base. The base begins with seven spare LRUs in stock and loses eight LRUs by the end of the horizon, leaving one missing from its aircraft. Since the goal is to have no more than two missing, the goal is met in this case. The number of LRUs lost is a random variable, and a portion of DRIVE's calculation is devoted to computing the probability that the asset position at the end of the horizon falls above the number of allowable holes for the LRU in the base's aircraft.

It is important to note that DRIVE is only concerned about the probability that the asset position at the end of the horizon is above the allowable holes line; the shape of the staircase does not matter. It fol-

lows that the effect of the base's receiving an additional LRU during the horizon is the same as if the base had started with one more LRU in stock, regardless of when the LRU actually arrives.

Two Levels of Indenture

Since the Ogden prototype of DRIVE was tailored to avionics items, the assumption of two levels of indenture fits well. Aircraft contain LRUs which, in turn, may contain SRUs. LRUs are repaired both at bases and at the depot, but SRUs replaced in LRUs at bases are repaired only at the depot. DRIVE does not consider components of SRUs, which usually are consumable items (often refered to as *bits and pieces*).

Repairs at Base Level

Because of our focus on avionics, this explanation may not apply to all kinds of components. A suspected faulty LRU that has been removed from an airplane may or may not be repaired at the base. There are several reasons why the base may not perform the repair locally. Some bases, particularly those with just a few aircraft, are not equipped to repair these LRUs. The necessary repair might simply be beyond the base's capability (such as replacing a wiring harness) or the base may not be authorized to work on the particular type of LRU. The base may already have made several unsuccessful attempts at repairing the particular LRU, indicating that deeper analysis of the problem should be made at the depot. In such cases, the LRU is declared NRTS and is sent to the depot.

The avionics items being considered are repaired on automatic test stations that perform sequences of tests. When a problem is detected, the equipment indicates that a particular SRU is at fault, and the repair consists of swapping the bad SRU with what is hoped to be a good one and running the test again. None of the SRUs dealt with by the Ogden prototype are repaired at base level; SRUs found to be faulty are declared NRTS and returned to the depot for repair.

The LRUs and SRUs are all *recoverable items*. This has two implications: (a) An attempt to repair them is made, although an item may be condemned at the depot as not economical to repair, and (b) when a NRTS item is returned to the depot, the base issues a requisition for a serviceable replacement. There is a rule that NRTS LRUs contain a full complement of their SRUs; bases do not retain SRUs from LRUs that they return to the depot.

Depot Versus Base Repair of LRUs

Most bases have the capability of repairing LRUs, which complicates computing the probability of the number of LRUs lost at a base during its planning horizon. For a base that does LRU repair, there are two modes of LRU failure depending on whether the LRU can be repaired at the base or if it has to be returned to the depot for repair. Therefore, the number of LRUs lost at the base is the sum of two random variables: the number that fail and are sent to the depot, and the number that fail but could be repaired at the base if there were sufficient replacement SRUs. Of course, if a base does not repair LRUs, DRIVE would be concerned only with LRUs sent to the depot for repair.

DRIVE deals with the first random variable—LRUs sent back to the depot for repair—in a simple, direct way. Computations about LRUs stuck in base repair, however, are more complex.

DRIVE's Model of the Failure and Repair Process

When avionics faults are noted on an aircraft, flight line technicians attempt to diagnose the problem and isolate it to one LRU. Typically, the LRU is removed from the aircraft in the belief that it is defective and sent to the intermediate repair shop for more comprehensive fault isolation and repair. Sometimes more than one LRU are removed from the aircraft to ensure that the fault is indeed eliminated. In any event, the intermediate repair shop uses a program-driven automatic test stand to attempt to identify the problem and repair the LRU(s). At intermediate level, the repair is sometimes made by straightening pins, cleaning connections, replacing fuses or other consumables, resoldering connections, or simply calibrating the LRU. Often, though, the LRU is repaired by replacing one or more defective SRUs, and the defective SRUs are sent back to the depot for repair. Sometimes, however, there is no serviceable spare SRU available at the base; in this case, the base submits a requisition for the needed SRU, and the LRU becomes AWP. As discussed above, sometimes the base cannot repair the LRU for whatever reason, and it is declared NRTS.

Thus there are four outcomes that can result from an LRU being removed from an aircraft because it is suspected of being defective: (a) it can be judged to be serviceable as the result of a bench check; (b) it can be repaired through minor maintenance or replacement of component parts; (c) it can be judged to be repairable but the base cannot effect the repair immediately owing to lack of serviceable repair parts

and it becomes AWP; or (d) it can be judged to be repairable but beyond the repair capability of the intermediate level, declared NRTS, and returned to the depot for repair. The number of LRUs that were serviceable at the start of the planning horizon will be reduced by the number entering intermediate repair and becoming AWP plus the number declared NRTS during the planning horizon.

From the depot's perspective, the first two of these several possible outcomes should not induce the allocation of any additional assets to the base. (The allocation of additional serviceable SRUs to replace any used in repair would be triggered in DRIVE only by the depleted SRU asset position and estimated future need for serviceable spare SRUs.) If the base needs one or more SRUs to alleviate an AWP condition in a repairable LRU, DRIVE will allocate such SRUs to the base if, and only if, an additional serviceable LRU is sufficiently valuable to warrant the cost of providing the SRUs to repair it.

The computations involved in dealing with AWP LRUs are more complex than those involving NRTS LRUs. DRIVE assumes that LRUs that can be repaired at the base are the result of SRU failures and that SRUs are cannibalized among LRUs. Thus, SRU failures are regarded as the primary events. Furthermore, the failures of individual SRUs are assumed to be independent events. As a result of these assumptions, the SRU/LRU relationship is similar to the LRU/aircraft relationship.[5] The number of LRUs of a particular type in base repair is inferred from the number of the various SRUs missing from LRUs in the following way. For each type of SRU, DRIVE computes the minimum number of LRUs needed to contain the SRU holes.[6] The cannibalization assumption implies that the number of LRUs in base repair is the largest of these quantities. Thus, the number of base-repairable LRUs lost to aircraft that are still in base repair at the end of the horizon for lack of spare SRUs at a base is determined by the asset position of the kind of SRU causing the most LRUs to be in that condition.

Because SRU failures are assumed to be independent, the probability that no more than a particular number of LRUs are lost due to a lack

[5]A different and perhaps more natural model would view LRU failures as the primary events, with SRU failures conditional on the number of repairable LRUs. That is, in fact, the way in which DRIVE views the SRU/LRU relationship when considering LRU repairs at the depot. This is described in the paragraph headed by "Inducting LRUs" under the subsection "DRIVE's Model of the Depot."

[6]SRU holes are inferred from unfilled requisitions for SRUs that reflect a 6L advice code, indicating that the requisition is for an asset needed to alleviate an AWP shortage.

of SRUs is the product of probabilities taken over SRU types. The individual probabilities are derived from the probability distributions of the number of SRUs failing during the horizon.

Among the depot's options is that of sending SRUs to bases to fill holes in LRUs in base repair. Such actions can increase bases' stocks of spar . LRUs or provide LRUs to fill holes in aircraft.

Negative Binomial Failure Probabilities

The probability that a base will meet its availability goal, given the base's spare stocks of LRUs and SRUs, depends on probability distributions of items failing at the base during the base's planning horizon. In the case of LRUs, the random variables are the number of LRUs sent by bases to the depot for repair. For SRUs, the random variables are the SRUs found to be defective in the bases' testing of LRUs and subsequently sent to the depot for repair.

DRIVE, like many other models used in logistics, assumes that these probabilities follow a negative binomial probability law. The negative binomial distribution has two parameters that can be set as functions of a specified mean and ratio of the variance to the mean, commonly called the VTMR.[7] The means of the distributions are calculated in step 2 of the overall DRIVE calculation. Choosing an appropriate VTMR is more problematic as the estimator has poor sampling properties, and observed VTMRs are very unstable over time (not to imply that the means are stable).[8] The Ogden prototype computes VTMRs based on a nonlinear regression proposed by Sherbrooke[9] that relates the VTMR to the expected number of failures per year. The formula is

$$VTMR = 1.0 + 0.14\ MEAN^{0.5}$$

[7]An idealistic view might lead one to suspect that the number of items failing in an interval could be described by a Poisson distribution. A great deal of empirical evidence, however, shows that the VTMR is typically greater than one, which is possible with the negative binomial distribution. In a theoretical sense, there are two ways in which the negative binomial distribution is related to the Poisson. A negative binomial distribution results when a Poisson process is compounded by a logarithmic distribution. The other way involves a Poisson process whose mean is sampled from a gamma distribution. It may be true that neither of these models supports a plausible explanation of the high VTMRs that are observed. It has been suggested that the part removal phenomena are locally Poisson, but the mean varies over time.

[8]Appendix A gives the results of an exercise to investigate the sensitivity of DRIVE to VTMRs.

[9]Sherbrooke, Craig C., *Estimation of the Variance-to-Mean Ratio for AFLC Recoverable Items*. Sherbrooke and Associates, Potomac, Maryland, January 27, 1984.

The negative binomial distribution has the probability density function

$$f(x) = \frac{\Gamma(r+x)}{\Gamma(r)\Gamma(x+1)} p^r (1-p)^x, \text{ for } x = 0, 1, \ldots$$

where $\Gamma(\cdot)$ is the gamma function ($\Gamma(n+1) = n!$ when n is an integer). Given a desired mean, μ, and VTMR, $v > 1$, the corresponding p and r parameters are

$$p = \frac{1}{v} \quad \text{and} \quad r = \frac{\mu}{v-1}.$$

DRIVE computes tables of negative binomial distributions using the recursion:

$$f(0) = p^r$$

and

$$f(x+1) = \frac{r+x}{x+1}(1-p)f(x), \text{ for } x = 0, 1, 2, \ldots.$$

Summary of DRIVE's Model of Bases

The following assumptions have been made:

- There are two levels of indenture: Aircraft contain LRUs, and LRUs may contain SRUs.
- Aircraft are repaired at bases by filling LRU holes, and LRUs are repaired by filling SRU holes. Successful repair of aircraft and LRUs by the end of a base's planning horizon depends only on having the appropriate hole-filling items at the base by the time the horizon ends.
- LRUs are cannibalized across aircraft and SRUs are cannibalized across LRUs.
- The number of failures of LRUs and SRUs at a base that need depot repair within a fixed time period are independent random variables with negative binomial distributions having variance-to-mean ratios as functions of the respective means.

- The number of LRUs that fail and are base repairable depend only on SRU failures, and their repair is only a matter of having spare SRUs available.
- All depot-level LRU and SRU repairs specified for the production period will be completed and the items will be delivered to their designated bases by the end of the bases' planning horizons. (Whether or not the depot has sufficient capacity to accomplish the repairs is not taken into consideration while priorities are determined in step 3. Constraints stemming from limited repair capacity are imposed later in step 4.)

The cannibalization assumption allows the base goals to be translated into allowable LRUs missing from aircraft for each base and type of LRU, and the probability that a base meets its goal is the product of probabilities that the base's LRU goals are met. Each of these probabilities involves the sum of two random variables: LRUs lost to depot repair and LRUs that enter base repair and do not emerge owing to lack of SRUs. The probabilities are derived from the distributions of item failures during the horizon and are functions of the initial stock, which may be negative, and the quantities of items shipped from the depot during the horizon.

Mathematical Description of DRIVE's Probability Calculation

Because the foregoing ideas are essential to the DRIVE prototype, the computation of the probability that a base meets its goal for an LRU is described here in more formal mathematical terms. One advantage of a mathematical representation is that it makes possible proofs of properties such as those described below under the heading "Some Relationships Among Allocation Actions."

In the following, we consider a single type of LRU at one base. We assume that the LRU contains n distinct types of SRUs, some of which may be present in multiple copies, and that all of the SRUs contained in the LRU are unique to that kind of LRU.

Number of LRUs unserviceable due to SRU holes. This is the smallest number of LRUs needed to contain all the SRU holes.

Using the subscript i ($i = 1,\ldots, n$) to differentiate among the n types of SRUs, let

q_i = number of copies of type i SRUs in the LRU;

h_i = number of SRUs of type i missing from LRUs; and

s_i = number of spare SRUs of type i in stock. (DRIVE assumes that holes are filled whenever possible, so that h_i and s_i are never both > 0.)

We define

a_i = the smallest number of LRUs that can contain the h_i SRU holes. Then

$$a_i = \text{integer part}\left[\frac{h_i + q_i - 1}{q_i}\right].$$

To see how the formula works, suppose $q_i = 3$. This maps $h_i = 0$ into $a_i = 0$, $h_i = 1$, 2, or 3 into $a_i = 1$, $h_i = 4, 5$, or 6 into $a_i = 2$, etc.

Cannibalization. The cannibalization assumption is that the number of AWP[10] (waiting for parts) LRUs in base repair is the smallest number of LRUs that can hold *all* the holes for the missing SRUs. Let this be a_0, which is

$$a_0 = \max_{i=1,\ldots,n} \{a_i\} .$$

Relation between failing SRUs and LRUs left in base repair. Suppose that X_i SRUs of one kind fail, leading to Y_i additional LRUs becoming AWP during the horizon and remaining AWP at the end of the horizon for lack of spare SRUs. The largest value of X_i that corresponds to a value of Y_i is given by

$$X_i = q_i a_0 - h_i + s_i + q_i Y_i .$$

The reasoning is as follows. The number of SRUs in the a_0 LRUs at the beginning of the horizon is $q_i a_0$. Of these, h_i are defective and $q_i a_0 - h_i$ are serviceable. Now add to this s_i more SRUs available for repairing LRUs, and we have $q_i a_0 - h_i + s_i$ SRUs that can fail during the horizon without causing any more LRUs to become AWP owing to failures of this kind of SRU. Between 1 and q_i additional SRU fail-

[10]The acronym AWP, for awaiting parts, is used to describe this condition. We shall use it from now on to avoid clumsy wording.

ures will require 1 more LRU in base repair than are AWP at the start of the horizon. And $q_i + 1$ through $2q_i$ additional SRU failures will require 2 more LRUs AWP, etc.

Probability that an SRU causes LRUs to be stuck in repair. Let $F_i(x)$ and $G_i(y)$ be the distribution functions of X_i and Y_i, respectively, as defined in the preceding paragraph. Given $F_i(x)$, the previous paragraph shows that

$$G_i(y) = F_i(q_i a_0 - h_i + s_i + q_i y) .$$

Probability distributions of LRUs stuck in repair. The probability that there will be no more than y LRUs AWP in base repair at the end of the horizon is the probability that none of the LRU's n SRUs are responsible for more than y LRUs AWP, so that

$$G_0(y) = \prod_{i=1}^{n} G_i(y) .$$

From this one can calculate the density function by subtraction:

$$g_0(0) = G_0(0)$$

and

$$g_0(y) = G_0(y) - G_0(y-1), \text{ for } y \geq 1 .$$

Probability that a base meets its goal for an LRU. This is the result that we have been working toward. In the notation below, the subscript 0 denotes the LRU.

A = largest number of LRUs allowed missing from aircraft at the base at the end of the horizon.

h_0 = number of LRUs missing at the beginning of the horizon;

s_0 = number of LRUs in stock at the beginning of the horizon plus the number sent to the base during the production period and assumed to arrive during the horizon;

X_0 = the number of LRUs removed from aircraft and sent to the depot for repair during the horizon;

$F_0(\cdot)$ = the probability distribution function of X_0;

Y_0 = the number of LRUs entering base repair during the horizon and still missing SRUs at the end of the horizon;

$g_0(\cdot)$ = probability density function of Y_0 as computed in the preceding paragraph;

Z_0 = $X_0 + Y_0$ is the total number of LRUs lost (i.e., failed and either NRTS or stuck in base repair during the horizon);

P = the probability that the base meets its goal for the LRU.

To meet the goal, the number of LRUs lost during the horizon plus the LRUs missing at the start of the horizon, minus the initial stock and minus LRUs sent to the base, can be no more than the goal. Using the notation just defined,

$$P = \Pr\left\{Z_0 \le A + s_0 - h_0\right\} .$$

Since Z_0 is the sum of two independent random variables, P can be computed by the usual convolution formula:

$$P = \sum_{z=0}^{A+s_0-h_0} g_0(z)F_0(A + s_0 - h_0 - z) .$$

DRIVE'S MODEL OF THE DEPOT

The preceding discussion has been concerned with modeling bases and the computation of the objective function. We now turn to consideration of the depot, which is where the actions that DRIVE helps plan take place. DRIVE considers a variety of actions at each stage of the marginal allocation process. The alternatives for providing additional assets to a base are:

- Send a serviceable LRU from depot stock.
- Complete the repair of an AWP LRU at the depot for which the needed SRUs are known. The required SRUs may be in stock, or they may need to be repaired.
- Induct an LRU into the repair process.
- Send a "package" of SRUs to a base where the set of SRUs in the package will allow the base to complete the repair of an LRU. The SRUs may be in stock at the depot or they may need to be repaired.

- Send an SRU, which may be available in depot stock. If it is not in stock, the SRU should be repaired.

The second and third options involving repairing LRUs require more explanation, but first let us introduce the notion of costs.

Repair Hour Costs

As discussed in more detail below, DRIVE employs a marginal analysis scheme that attempts to achieve the largest possible value of its availability-related objective function for the repair resources expended. DRIVE assumes that hours available in a production period on the LRU test stands and in the SRU repair shops are the limiting resources. Therefore, the standard hours required for repairs are used in the marginal analysis. We use the term *cost* in a generic sense to refer to such data even though the units are hours rather than dollars. If, however, it were determined that dollar budgets were generally more constraining than physical capacity, standard costs could easily be used instead of standard hours. The following paragraph describes how DRIVE associates costs with the various alternative depot actions.

For the repair of an SRU, the cost is the standard hours to repair the item. Serviceable SRUs and LRUs that can be taken from depot stock are arbitrarily given a cost of one hour to make them appear cheap. The reasoning is that DRIVE's purpose is to prioritize repair actions, and the depot should not repair something if a serviceable item is already available. For packages, the cost is the sum of standard repair hours for the SRUs in the package that have to be inducted, and one hour for every SRU taken from stock. Completions of AWP LRUs that have already been inducted and diagnosed bear the cost of the LRU standard repair hours plus the cost of the package of needed SRUs. For LRU inductions, the cost is the standard repair hours for the LRU plus an expected number of standard hours for the SRUs. The expectation is based on replacement factors, which represent probabilities that the various SRUs will be needed.

Repairing AWP LRUs

Unlike bases, the Ogden shop that repairs LRUs does not normally cannibalize SRUs. For those LRUs that have been inducted and for which faulty SRUs have been identified, DRIVE is provided with information about what SRUs are needed. DRIVE assumes that the information is complete and correct, i.e., supplying the missing SRUs is

sufficient to repair the LRU.[11] For each unfinished LRU, DRIVE evaluates the cost of repair, including the cost of supplying missing SRUs. When choosing to finish an LRU, it picks the one that can be repaired at least cost. The total costs are updated at each step to correct for costs of SRUs that may no longer be available from stock.

Inducting LRUs

When an LRU is to be inducted, there is only probabilistic information about what SRUs will be needed. Although DRIVE evaluates the cost through an expected-value calculation based on probabilities that individual SRUs will be needed, we want to have some assurance that needed SRUs will be available. Thus, DRIVE may request the repair of SRUs in conjunction with the induction of an LRU. This is done in the following way.

One of the user-supplied inputs to step 2 is a goal specified as the probability that there will be sufficient SRUs available for however many LRU inductions for each type of LRU are called for on the priority list. The total number of each kind of SRU that may have to be replaced in the number of LRUs inducted so far is treated as a binomial random variable where the number of trials is the number of LRUs, and the probability of success (i.e., needing an SRU) is the replacement factor for the type of SRU. Given the number of SRUs already allocated for prior LRU inductions, the probability that there will be enough of each kind can be computed. The product of these probabilities taken over the SRUs of each kind is compared to the specified target probability. If the computed probability is too low, DRIVE will ask for one more of some SRU to be allocated to the LRU shop. This step is repeated until a satisfactory probability is reached. The choice of which additional SRU to supply is made by a "mini-DRIVE" marginal allocation procedure that works as follows. For each SRU, calculate the logarithm of the ratio of probabilities with and without the additional SRU. Divide the logarithm by the SRU's repair cost (or one hour if an SRU is in stock). The SRU that yields

[11] This assumption is questionable. LRUs are repaired on computer-driven test stands and the process is sequential. When a faulty SRU is indicated, the SRU is replaced and the test is started over. To diagnose an LRU completely requires that serviceable spare SRUs be available. Although "shop standard" LRUs are not authorized for these items, we have been told that the shop sometimes keeps the "last good one" in order to borrow its SRUs for testing other LRUs. The alternative is when a faulty SRU is indicated, to put the LRU aside until a replacement SRU is obtained. Whenever that is done, the assumption leads to an underestimate of what is needed to repair an LRU.

the highest value is chosen. This calculation results in the least expenditure of SRU repair hours for the probability achieved.

Packages of SRUs for Repairing LRUs at Bases

If there are SRUs missing from LRUs at a base, sending a package of SRUs sufficient to allow the repair of one LRU is a possibility. The number of needed SRUs of each kind is calculated in the following way. The cannibalization assumption implies that the SRU holes are consolidated into the minimum number of LRUs, and we want to figure out how many holes are in the LRU that has the fewest missing SRUs. If, for SRU type i, $a_i < a_0$, the LRU is not missing any of its SRUs of type i (because a_i is the number of LRUs needed to contain h_i holes, but there are more than that many AWP LRUs). When $a_i = a_0$, all AWP LRUs except possibly the one we are interested in are missing all of their type i SRUs. This accounts for $q_i(a_0 - 1)$ of the h_i holes. The rest of the holes, equal to $h_i - q_i(a_0 - 1)$, are in the LRU we are considering.

The cost of a package is figured in the same way as for SRUs required to complete the repair of an AWP LRU at the depot—standard repair hours for SRUs that need to be repaired and one hour for those that are available in depot stock.

Sending an SRU to a Base

In addition to packages of SRUs (which may contain only a single SRU) to repair AWP LRUs, DRIVE considers sending single SRUs to bases to be held in stock as protection against future needs.

Bias Toward AWP LRUs

We believe that it is preferable to repair LRUs at the depot that have already been inducted into repair shops and whose needs for SRUs have been determined before inducting additional repairable LRUs. And we judge that AWP LRUs at bases should be given preference over AWP LRUs at the depot when both options have comparable payoffs.[12] To these ends, we introduced a heuristic adjustment to costs associated with packages of SRUs for bases and for completing

[12]The main consideration is that in many cases, LRUs are scarce items and valuable resources in themselves such that the broken ones should be fixed expeditiously. Furthermore, AWP LRUs at bases can be fixed and made available more quickly than AWP LRUs at the depot, and we do not want to be sending LRUs to bases when the bases have AWP LRUs that they can fix themselves.

repairs of AWP LRUs at the depot. In the discussion of costs, we indicated that the cost of an LRU induction at the depot was the standard hours for the LRU repair plus an expected value for its SRUs based on replacement factors and SRU repair hours. In the case of AWP LRUs, DRIVE sets an upper bound on the repair cost that is slightly less than the cost of an LRU induction. In turn, the bound for packages of SRUs is slightly less than the bound for the depot's AWP LRUs. If the computed cost in either of these cases is less than the bound, DRIVE uses the computed cost. Otherwise, DRIVE uses the bound.

Carcass Constraints

Carcass is the colloquial term for a defective item that can be repaired. Obviously, a repair can take place only if there is a repairable asset available. DRIVE can be run with or without imposing constraints on prioritizing repairs for items beyond the number of carcasses currently available in the depot. The Ogden prototype, however, does not impose SRU carcass constraints on LRU inductions. That is, it does not decide to cancel the induction of an LRU because the SRUs asked for in the mini-DRIVE calculation are not available. But when the mini-DRIVE does request SRU repairs, the corresponding SRU inductions are counted against available SRU carcasses.

Updating Depot Data

As DRIVE selects repair and distribution actions, it updates a running count of available stock and carcasses for LRUs and their component SRUs at the depot. For SRUs, the stock is divided between regular depot stock and SRUs that have already been allocated for use by the LRU repair shop.[13]

When an item is allocated from stock, the corresponding stock counter is reduced. In the case of SRUs utilized in depot LRU repair, stock already allocated to the LRU shop is depleted before the regular stock. When an item is inducted, its carcass count is reduced. When a specific AWP LRU at the depot is selected for completion, that LRU's record of SRU holes is marked to indicate that it cannot be selected again.

[13]These assets are in a storeroom just off the shop, and are much more readily available than items that have to be requested from depot supply. The storage place is called the DMSC for depot maintenance support center.

Updating Bases Receiving Items

Internally, DRIVE maintains data on the asset position for each LRU at each base. For an LRU and all its component SRUs at a base, there is a count of stock on the shelf and of numbers of items missing from higher assemblies (SRUs in LRUs and LRUs in aircraft). When DRIVE chooses to send an LRU or some SRUs to a base, this increases the stock counts for the items at the receiving base. Then a series of logical steps is undertaken. The number of LRUs in base repair is computed from the array of SRU holes. Then if, for any SRU, both stock and holes are positive, the stock and holes are both reduced until one reaches zero. This action enforces the assumption, consistent with cannibalization, that there will not be both stock on the shelf and holes. The computation for LRUs in base repair is repeated because some SRU holes may have been filled. If the number of LRUs in base repair is now less than the number originally computed before filling holes, the difference is assumed to be an increase in LRU stock. If necessary, we make an adjustment to invoke DRIVE's rule that there cannot be both LRUs missing from airplanes and stock on the shelf.

The stock and holes data are the basis for the probability computations described in the discussion of DRIVE's model of bases. The machinations described in the previous paragraph reinforce the idea that for purposes of evaluating the objective function, all we care about is bases' asset positions at the end of their horizons, and it does not matter when during the horizon items are allocated to a base.

Some Relationships Among Allocation Actions

From the previous mathematical description of the probability computations, we can derive some relationships between the effects of alternative depot actions. The four properties of DRIVE's probability calculation below may not agree with one's first intuition.

1. If there are any SRU holes at a base, the effect of sending the base exactly the set of SRUs contained in an LRU is identical to sending the base an entire LRU. This may be counterintuitive because in one case, the base receives the "box" plus the contents, and in the other, the base gets only the contents. The mathematics shows, however, that because the base has SRU holes, there is at least one broken LRU at the base, and sending only the SRUs gives the base another operational LRU. Also, the number of serviceable SRUs at the base is the same in both cases.

2. If, however, there are no SRU holes at a base (meaning there are no AWP LRUs in base repair), sending an LRU is better for the base than sending only an LRU's complement of SRUs. While both options give the base the same increased protection against SRU failures, sending a whole LRU also gives the base added protection against an LRU failure requiring depot repair. (This is not true in the previous case, where the base has LRUs in base repair.)
3. Sending a package of SRUs that will allow the base to repair one of its AWP LRUs is not as beneficial to the base as sending a whole LRU, even though the base gains a serviceable LRU either way. This is because the base gets more SRUs in the LRU than with the package (unless the package is a full complement of SRUs, in which case the first property applies).
4. Consider two bases that are identical in all respects, except that base A has no SRUs missing from LRUs, and base B has some SRU holes. The stocks of items on shelves is the same for both bases. Base B then has a better asset position than base A. The reason for this is that DRIVE infers that base B has LRUs in base repair while base A has none. The AWP LRUs at base B are assets that can be the source of SRUs for cannibalization.

DRIVE'S OPTIMIZATION ALGORITHM

The marginal analysis scheme used by DRIVE to generate sequences of repair and distribution actions is patterned after optimization methods employed by other normative models in logistics, particularly models that allocate stock levels of spare parts.[14] The situation in DRIVE is a bit more complex than other applications, however, and we do not claim strict optimality.

Marginal Analysis in General

Informally speaking, marginal analysis is appropriate, as shown in Appendix C of the LMI report just cited, in the following kind of problem. There are potential supplies of n kinds of items, indexed by i, with an item of type i having cost c_i. For each i, there is a function, $f_i(x_i)$, representing the payoff for allocating x_i units of item i, and the overall objective function for the allocation of $x_i, \ldots, x_n$ items

[14]One comprehensive example is the Logistics Management Institute's Aircraft Availability Model. A technical description may be found in O'Malley, T. J., *The Aircraft Availability Model: Conceptual Framework and Mathematics*, Logistics Management Institute (LMI), Bethesda, Md., June 1983.

is $f_1(x_1) + f_2(x_2) + \cdots + f_n(x_n)$. If the functions $f_i(x_i)$ are concave, meaning each increment in x_i produces a smaller increase in f_i than the preceding increment, then an *efficient* allocation may be achieved in a stepwise manner. At each step, choose the item i for which an increment in x_i produces the largest ratio of increase in payoff to cost, and increase x_i by 1. The ratios $[f_i(x_i + 1) - f_i(x_i)]/c_i$ are called sort values. By efficient we mean that at any point on the sequenced list of allocations, for that total cost, the objective function will be maximized. Conversely, for that value of the objective function, the algorithm will achieve the minimum cost allocation. It is significant that the objective function can be expressed as a sum of concave functions.

Application to DRIVE

The DRIVE objective function is a product of probabilities indexed by kind of LRU and base. If there are, say, 30 kinds of LRUs and 20 bases, there are 600 factors in the product. Ignoring SRUs for now, we regard the items to be allocated as LRUs to bases. The product form of DRIVE's objective function can be converted to the additive form required by the theory by taking logarithms. The numerator of a sort value associated with the allocation of an LRU to a base is the difference in logarithms of probabilities that the base's goal for the kind of LRU is met with and without the additional LRU. If $P_{lb}(x)$ is the probability that base b meets its goal for LRU l with x LRUs in stock, the numerator of the sort value is $\ln P_{lb}(x+1) - \ln P_{lb}(x)$. The denominator is the cost of supplying an LRU.

At variance with the previous description of marginal analysis is the fact that the cost of supplying a particular type of LRU can change as more LRUs are allocated. But since DRIVE will first allocate LRUs from depot stock, then complete the repair of AWP LRUs, and finally induct new LRUs, the costs do not decrease with successive allocations of a particular LRU, so the marginal allocation should still be correct.

Other complications arise because, in addition to allocating LRUs, the depot also sends single SRUs and packages of SRUs to bases. Furthermore, with the inclusion of SRUs, the terms in the objective function are not necessarily concave as required by the theory. This

happens because the value of sending an SRU depends on a base's status with respect to other SRUs.[15]

DRIVE'S COMPUTATIONAL SCHEME

Every allocation decision involves sending one or more items to a base and may or may not require repair actions. Also, repairing LRUs at the depot may require allocating SRUs to depot shops. DRIVE produces separate output files specifying repair priorities and distribution recommendations. To ease the computational burden, DRIVE considers one LRU family, i.e., an LRU and all of its SRUs, at a time. Each repair action is remembered along with its associated sort value, which is used later as the basis of merging together the repair actions for all LRUs. The repair actions need to be merged because the repair priority lists that are ultimately produced are organized by repair shop and test stand. Information about allocations of items to bases, however, does not need to be merged in this way because in preparing distribution priority lists, we want the data to be segregated by LRU family. (Some sorting to group distribution actions for SRUs is necessary, but this is handled in step 5, when the priority lists are produced.)

Processing a single LRU family (i.e., an LRU and its component SRUs) is done in a sequence of 5 phases:

1. Read data about the LRU family.
2. Supply LRUs to bases for which there are holes in airplanes.
3. Supply LRUs to bases with poor asset positions.
4. Perform normal DRIVE allocations.
5. Merge repair actions for the current LRU family with those of previously processed LRUs.

Phase 1: Read Data for an LRU Family

The information provided for an LRU and its constituent SRUs is listed below:

[15]Consider a case where an LRU has two SRUs and a base has no stock or holes for either SRU. The increase in the objective function resulting from allocating a type 2 SRU is greater after the base has been given a type 1 SRU than before. This can lead to two successive allocations where the improvement from the second allocation is more than from the first allocation. The introduction of packages serves partially to eliminate this kind of difficulty.

Item Relationships

- LRU, SRU parent and child relationships.
- Number of copies of the LRU in an aircraft.
- Number of copies of the SRU in its parent LRU.

Production Data

- Indicator of required repair resource (LRU test stand or SRU shop).
- Standard hours for repair.
- Replacement factor (probability of replacement) for SRUs.

Depot Asset Position

- Serviceable LRUs and SRUs in depot stock.
- Number of SRUs in DMSC stock.
- Unserviceable carcasses and number in repair (these are added together).

Status of AWP LRUs in the Depot Shop

- Number of diagnosed AWP LRUs in depot repair.
- Number of SRUs of each kind missing from each AWP LRU.

Base Asset Positions

- Number of serviceable LRUs and SRUs in stock at each base.
- Number of each LRU and SRU missing from higher assemblies at each base.
- Number of each LRU in maintenance at each base.[16]

Goals

- Number of LRUs allowed to be missing from aircraft at each base at the end of the base's horizon (derived from base goals, number of aircraft at bases, and number of copies of LRUs on an airplane).

[16]The excess over the number that can be accounted for by SRUs missing under the cannibalization assumption is added to serviceable stock. Until diagnosed, we want to count them as base assets.

Expected Demands

- Expected number of LRUs and SRUs at each base that will be returned to the depot during the horizon. These are the data used to compute the probability distributions employed in calculations of the objective function.

Phase 2: Supply LRUs to Bases with LRUs Missing in Airplanes

As used in the Ogden demonstration, this function is never exercised because if there really are holes in airplanes, exceptional measures are taken outside of DRIVE to fill the holes. The original idea, however, was that if a base has more holes for an LRU at the start of the horizon than the goal permits, the probability for the LRU-base combination would be zero, and the normal DRIVE allocation mechanism would be meaningless. Since holes in aircraft are regarded so seriously, this phase was designed to eliminate all LRU holes, regardless of base goals. This is a departure from aircraft availability goals by policy intervention.

The logic is to fill all holes at bases for an LRU, with priority given to bases according to the ratio of number of aircraft held down by the LRU to the number of aircraft at the base. For an action to fill a hole in an aircraft at a base, the sort value is taken to be the fraction of airplanes down at the base plus 2.0. Adding 2.0 makes these actions highest priority when the repair actions for the different LRUs are merged.[17]

When a base is selected to receive an LRU and none is available in depot stock, DRIVE evaluates three possibilities: (1) Send a package of SRUs to the base to repair one of the base's AWP LRUs, (2) finish the repair of an AWP LRU at the depot, and (3) induct an LRU at the depot. The option with the lowest cost in repair hours is chosen. If none of the options is feasible because of carcass constraints, DRIVE will indicate that an LRU be inducted so that priority calculations can be made and the algorithm can proceed.

[17]There is no guarantee that "normal" DRIVE sort values are less than 1.0, but that is almost always the case.

Phase 3: Supply LRUs to Bases with Poor Asset Position

This is a heuristic we added to DRIVE to counteract a behavior that appeared undesirable. We had observed cases in which there were bases with large expected demands and relatively sparse asset positions competing with bases with very small expected demands. Under these circumstances, supplying an LRU to the base with the large demand would produce a small gain in the objective function compared to supplying an LRU to the other base, whose probability was already high because of the small demand. Thus, an allocation might be made to a base that seemed relatively unimportant, when another base that looked like it needed more help would go begging.

To inhibit such behavior, before the normal DRIVE allocation algorithm is invoked, DRIVE may supply LRUs using the three options described under phase 2. Low probability of meeting the goal is the criterion for setting priorities. The test for whether to consider a base for this treatment relates to the probability of meeting the goal as a function of the number of LRUs in stock at a base. When regarded as a function of the LRU stock, the increments of probability should be increasing when adding to very low values of stock, and should be decreasing for larger values of stock.[18] Among the bases whose probability functions are marginally increasing, the base with the lowest probability is chosen to be supplied with an LRU. This is repeated until no bases qualify for such treatment. The sort value associated with these actions is the probability subtracted from 2.0. That gives priority to low probabilities and sequences these actions after filling holes in aircraft and before normal DRIVE allocations.

Phase 4: Perform Normal DRIVE Allocations

Once DRIVE determines there are no (more) bases with poor asset positions, it allocates assets using the marginal analysis procedure previously described. For an LRU family, the process terminates under one of three conditions: (1) The sort-value of an allocation falls below a user-specified threshold, (2) the product of base probabilities for the LRU family goes above a user-specified value, or (3) no more allocations are possible because depot stock has been exhausted and

[18]Many probability functions exhibit this behavior; they are convex for low values of their arguments and concave for high values. The test used by DRIVE to determine if a base is in a "bad" asset position relative to a particular LRU comes from the definition of convexity. Let $F(s)$ be the probability of meeting the availabilty goal when the number of LRUs in stock is s. The base is deemed to be in a poor asset position relative to the LRU in question if $2F(s + 1) < F(s) + F(s + 2)$.

there are no more assets that can be repaired. It might be desirable to be able to terminate the allocation process with a criterion related to the amount of repair resources consumed. This is not possible, however, because the computations deal with one LRU family at a time. Experience should allow users to set reasonable sort-value thresholds that result in sufficiently large numbers of repair actions without wasting computer time.

Phase 5: Merge Repair Actions Among LRU Families

Because DRIVE does its priority computations one LRU family at a time, the repair actions across all LRU families must be merged to make a unified priority list. Merging follows completion of the priority computations for each LRU family beyond the first so that the sort values run from high to low.

As mentioned previously, the sort values associated with the set of repair actions for an LRU family may not be strictly decreasing. If not corrected, this would interfere with the merging process. If some repair action has a low sort value followed by actions with higher sort values, the repairs would get "stuck" on the low value and the subsequent repairs would come out farther down on the merged list than they should. The remedy is to adjust the sort values as necessary prior to merging.[19]

The material in this section is embodied in a computer program called LSRU.[20] The inputs and outputs to LSRU are described in detail and illustrated in Appendix C.

The next section explains how data for the LSRU program are prepared, and Sections 4 and 5 discuss the uses made of the outputs from LSRU.

[19]The process has been called *convexification*. Think of a graph of logarithms of probabilities versus cumulative cost. Each repair action corresponds to a point on the graph. Convexification consists of adjusting sort values so that points falling below the convex hull of the graph are raised.

[20]LSRU is a contraction of LRU and SRU.

3. PRELIMINARY CALCULATIONS

As we have indicated, the first step in the DRIVE process is extracting information from Air Force standard data systems and specially maintained data files using a preprocessor; the priority calculations are a third step. Standing between steps 1 and 3 is a computer program called DRINP, for "*DR*IVE *inp*ut."

The preprocessor was developed by personnel at the Ogden ALC, while the rest of the DRIVE prototype was constructed at RAND. In order to retain flexibility for future enhancements and to facilitate verification, we specified that the output of the preprocessor would contain more information than DRIVE actually requires, especially with respect to item and base identifiers. As a result, the output from the preprocessor is a rather bulky file. Introducing an intervening step between the preprocessor and the optimization algorithm to distill the data and do some preliminary calculations simplified the implementation of the prioritization logic and allowed us to work with a smaller, faster, and less complicated program that used concise, manageable data.

APPROXIMATIONS IN THE PRIORITY CALCULATIONS

Although much of DRINP's work consists of simple arithmetic and reformatting, DRINP is responsible for invoking adjustments and approximations that the priority calculation relies upon for its somewhat simplified view. There are four kinds of situations to be dealt with:

1. There are four series of F-16 aircraft. The C and D series have, for the most part, different avionics than do the A and B series, although the items repaired at Ogden are mostly for the A and B series. The algorithms employed in step 3 do not recognize the distinctions among series.
2. Even within a series, it is possible that aircraft have more than one configuration. For example, there are several versions of radar antennas.
3. Some units have wartime missions that call for them to deploy without LRU repair capability, taking with them war readiness spares kits to sustain them until repair capability is restored. In practice, units do borrow items from their WRSK to support

peacetime flying when the items are not available from primary operating stock. This implies that items can be missing from WRSK. The problem for DRIVE is mediating between filling one base's WRSK versus supporting another base's peacetime flying program. Lacking any clear guidance about how to do this, DRIVE has its own way of reconciling allocations between POS and WRSK.

4. There are some SRUs that are common to more than one LRU. This is a problem because the priority algorithm is structured so that it considers one LRU family at a time. The difficulty here is attributing common SRU assets and holes to their various LRU parents.

The priority computation in step 3 does not deal directly with these four conditions. Rather, it operates on expected demands for LRUs and SRUs at bases and allowed numbers of LRUs missing at bases. Thus, part of the job of step 2 is to calculate these quantities appropriately to deal with the four conditions in reasonable ways. That issues of configuration (the first two conditions) can be dealt with by manipulating demands and goals is a result of DRIVE's cannibalization assumption. Below, we explain how DRINP computes expected demands and availability goals for LRUs to deal with the first three situations. Then we describe the approximation employed to cope with the problem of common SRUs. The section concludes with a list of the data items that are contained in the output of the preprocessor and utilized in step 2.

EXPECTED DEMANDS

Demand for an item is the number returned to the depot from a base during the base's planning horizon. As related in Section 2, expected demands are the basis for calculating the probability distributions used in the priority computation. DRIVE assumes that the expected demand for an item at a base is the product of a demand rate, a NRTS rate, and the operating hours for the item at the base during the horizon. Demand rates are obtained from D041, the Recoverable Consumption Item Requirements System, and are a data item called the organizational and intermediate maintenance demand rate (OIMDR). The OIMDR represents the number of removals per 100 hours of operation. Given the assumption that expected demands are proportional to usage, DRINP has to estimate hours of operation for each item at each base, and this involves the first three concerns mentioned above.

WRSK Versus POS

One solution to the dilemma of allocating items to fill holes in WRSK versus making them available for bases in support of peacetime flying would be to delay allocating items for POS until all WRSK requirements are filled. Such a solution, however, might seriously degrade the capabilities of bases without WRSK authorizations. We are concerned, in particular, that training bases—which have sizable flying programs—would often find themselves short of critical items. DRIVE deals with the problem of providing adequate war reserve protection, while also furnishing items for peacetime flying, by manipulating expected demands in conjunction with setting the aircraft availability goals for the bases.

The current policy with regard to WRSK for F-16 units is that they should have LRUs to support operations for 30 days of wartime flying without benefit of resupply. To make bases with WRSK ready to go to war, DRIVE assumes that they will fly their peacetime programs until the ends of their horizons and then fly for 30 days at wartime rates. Thus, the expected demands for items at WRSK bases are increased by including wartime flying hours into the multiplier of items' OIMDRs. But since WRSK bases are not expected to have all aircraft fully operational at the end of a wartime scenario, we generally specify lower availability goals for them. In the Ogden demonstration, the operators of DRIVE typically specify 100 percent goals for the non-WRSK bases and 85 percent for the WRSK bases.

Depot Demands for LRUs

In calculating hours-of-operation multipliers of the OIMDR, the first two problems, relating to variations in aircraft configuration, must also be taken into account. The computation of expected demand for a given LRU at a specific base goes as follows (to simplify notation, the base and LRU are not indicated). We use lowercase identifiers to represent data obtained from the preprocessor and uppercase symbols for quantities calculated by DRINP.

The peacetime flying hour program is specified in terms of the bases' hours per month. These are adjusted for planning horizons, which are calculated in the following way:

t_d = nominal depot lead time, specified by the user when DRINP is run. In the Ogden demonstration, this is set to 18 days to represent the sum of the age of the asset position data, time to have repairable carcasses delivered

to the shops (induction lead time), and half the length of the production period.[1]

t_0 = base-specific order-and-ship time.

T = base-specific planning horizon = $t_d + t_0$.

The monthly peacetime flying hours at a base are specified by series. To relate flying hours to LRU usage, we must take into account the number of copies of the LRU on the aircraft and the proportion of aircraft of a given series that uses the item (problems 1 and 2). Let

s = index of aircraft series (A, B, C, D).

f_{ps} = peacetime flying program for the base in flying hours per month (30 days) for series s aircraft.

q_s = number of LRUs of this type on a series s airplane.

a_s = fraction of series s airplanes at the base that have the LRU.[2]

U_p = operating (U for "utilization") time for the LRU at the base in hundreds of hours during the base's planning horizon. This is

$$U_p = \frac{T}{(30)(100)} \sum_s q_s a_s f_{ps} .$$

For wartime operations:

f_{ws} = flying hours in 30 days of wartime activity for series s aircraft at the base.

U_w = operating time for the LRU at the base in hundreds of hours for the base's wartime plan.

[1]Appendix C gives the results of an exercise to show the sensitivity of numbers of items included in a typical priority list to a range of values for depot lead time.

[2]This quantity varies by base. Unfortunately, only worldwide averages are available to the Ogden prototype, although DRINP is programmed to accept base-specific fractions if they are available.

This is

$$U_w = \frac{1}{100} \sum_s q_s a_s f_{ws} \ .$$

U_w will be zero for bases that do not have wartime deployment missions (i.e., non-WRSK bases). Since the OIMDR covers all removals, and the expected demands we are after are only those for which bases send unserviceable LRUs to the depot, we must adjust U_p and U_w for the fraction of LRUs removed that are sent to the depot. Also, some bases are not equipped to repair LRUs at all. To make these adjustments, DRINP gets the following data:

b = fraction of LRUs of this kind removed from aircraft that get repaired at the base. (This is 1.0 minus the NRTS rate.)

r_p = 1 if the base repairs LRUs in peacetime, 0 if not.

r_w = 1 if the base repairs LRUs in wartime, 0 if not. This is normally 0 in the Ogden demonstration because bases with WRSK usually do not have repair capability in wartime and DRIVE does not consider wartime flying for non-WRSK bases.

The overall expected demand at the depot for the type of LRU in question at the base is

$$D_{LRU} = \left[\left(1 - r_p b\right) U_p + \left(1 - r_w b\right) U_w \right] \text{OIMDR} \ .$$

The factors $(1 - r_p b)$ and $(1 - r_w b)$ say that if the base repairs LRUs, the depot will expect to see $1 - b$ fraction of the LRUs removed. If the base does not have LRU repair capability, the depot will see all the LRUs removed from aircraft at the base.[3]

[3]This assumes that bases that do not repair LRUs in peacetime send their defective ones to the depot. It is more likely that they send their LRUs to another base for repair. For the set of items in the Ogden demonstration, however, almost all bases do have repair capability, and those that do not are not very active.

Demands for SRUs

The D041 system also computes an OIMDR for SRUs. Letting q be the number of copies of an SRU in its parent LRU, the expected demand at a base for an SRU belonging to an LRU is

$$D_{SRU} = q\left(r_p U_p + r_w U_w\right)\text{OIMDR} ,$$

where U_p, U_w, r_p, and r_w are as defined for the parent LRU. The formula is used because the operating hours of an SRU are q times the operating hours of its parent LRU. Multiplying the U quantities by the corresponding r indicators asserts that if the base does not repair LRUs $(r = 0)$, there will be no need for SRUs at the base.

AVAILABILITY GOALS FOR LRUS

In Section 2 we pointed out that bases' availability goals could be translated into numbers of LRUs that could be missing from aircraft. If all airplanes at a base were configured in the same way with respect to an LRU, determining the allowable LRUs missing would be straightforward. Suppose a base has 40 airplanes, each with 3 of an LRU, and the base's goal were 85 percent available aircraft. The allowable number of LRUs missing would be $0.01(100 - 85)(3)(40) = 18$. That is, 15 percent of the airplanes is 6 allowed down, and the 6 airplanes contain 18 LRUs. To allow for condition 1, where the LRU may be present in different quantities on different series of aircraft, the allowable number of LRUs missing from airplanes is the sum of the allowable number for each series. This assumes that the base would cannibalize LRUs across series as well as within series. A mathematical representation of the computation is as follows. Let

g_s = stated availability goal for a base as a percent of its series s airplanes that should be complete. This is data given to DRINP. (As implemented at Ogden, however, all series aircraft at a base are assigned the same availability goals.)

n_s = number of series s aircraft at the base.

q_s and a_s as defined previously: the quantity per application and the fraction of aircraft of series s in which the item is installed.

The allowable number of LRUs missing from aircraft at the base is

$$A = \text{ceiling}\left[\sum_{s} \frac{100 - g_s}{100} q_s a_s n_s\right]$$

This procedure is not quite correct in the presence of the second condition where aircraft of the same series at a base may utilize different LRUs for the same purpose. Continuing with the example above, suppose all 40 aircraft are of the same series, but half have LRU type 1 and the other half have LRU type 2. Then the allowable LRUs missing would be nine for each type, equivalent to three airplanes down. This is more restrictive than asking for any combination of the two types of LRUs missing that would lead to no more than six aircraft down.[4]

Adjusting Goals at WRSK Bases

DRIVE's approach to mitigating between POS and WRSK results in bases without wartime deployment missions having low expected demands and high availability goals (typically 100 percent), and the deploying bases having high demands and lower goals. DRIVE could allocate fewer assets to a WRSK base than would be allocated to the base were the base treated as a non-WRSK base with a higher goal and smaller expected demands. It is as though we would allow WRSK bases to be in worse condition at the end of their peacetime horizons than we would if the bases did not have wartime missions.

DRIVE is usually prone to this difficulty only with LRUs that are used in multiples on airplanes. If there are four LRUs, say, on each airplane, and one LRU is removed, the base is provided three more that can be cannibalized. And if the base is allowed eight airplanes down, 32 LRUs could be missing, and the goal for the LRU at the end of the wartime horizon would still be met. This might well be less rigorous than if we were to allow no LRUs missing at the end of the peacetime horizon, even with much lower expected demands.

The most satisfactory way to deal with this problem from a modeling perspective would be to assign two goals to the wartime bases: one

[4]We do not have sufficient data to judge how serious this problem is. It may be that aircraft within a series at a base are homogeneous—they would all have the same kind of radar antenna, for example. Indeed, the real problem at Ogden is that we do not yet have base-specific application percentages, and using worldwide values for all bases is surely wrong.

for peacetime flying during the normal horizon and the second to apply to the extra 30 days of wartime operations. The objective function would be in terms of jointly meeting both goals. We have not introduced this approach into the Ogden prototype as it requires a great deal more arithmetic on the part of the priority algorithm where the computer spends most of its time. Instead, the Ogden prototype makes a simplistic downward adjustment to the allowable number of LRUs missing at a base when it appears that the problem will arise. The idea is to set the goal for missing LRUs to be at least as hard to meet as the goal for the base would be if the base were not a WRSK base.

Using the negative binomial assumptions discussed in Section 2, DRIVE computes the probability that no LRUs will be removed from aircraft and sent to the depot using the base's peacetime demand rate for the LRU. No NRTS action for the LRU is assumed to correspond to a 100 percent availability goal. Call this result $P_p(0)$. Then the cumulative distribution function of the negative binomial distribution is calculated using the overall demand (peacetime plus wartime) for points 0 through A, where A is the original allowable number of LRUs missing. Call this function $P_w(x)$, for $x = 0, 1, \ldots, A$. The largest x such that $P_w(x) \leq P_p(0)$ is used instead of A for the allowable number of LRUs missing. This adjustment is made without regard to base asset positions. Most of the time it turns out that $P_w(A) \leq P_p(0)$, and no adjustment is necessary.

SRUS COMMON TO MORE THAN ONE LRU

The existence of SRUs that are constituents of more than one kind of LRU is a problem because the priority-setting calculations deal with one LRU family at a time. The difficulty lies in attributing SRU assets to specific LRUs when, in fact, an SRU could be used to repair several different kinds of LRUs. The affected data are:

Depot Assets

Unserviceable LRU and SRU carcasses on hand.
SRUs inducted into repair.
Serviceable SRUs in depot stock.
Serviceable SRUs in the DMSC (depot maintenance support center).

Base Assets

Stock.
SRUs missing from LRUs at bases.

DRIVE deals with common SRUs by allocating the totals according to expected demands. At the depot, a common SRU related to a particular LRU is assigned a weight equal to the parent LRU's expected demand (NRTS) multiplied by the replacement factor for the SRU in the LRU. The weight divided by the sum of weights over all applications of the SRU is applied to each of the four kinds of data. For a base's asset position, a similar allocation scheme is used, but the weights are the expected demands of the SRUs at the base. The effect of allocating common SRUs in this way is to disregard the flexibility of being able to utilize SRUs for several different LRUs, and DRIVE will likely try to supply more of such SRUs than it really should.

The correct approach would be to have DRIVE simultaneously treat all LRUs sharing SRUs in the marginal allocation process. This would, however, greatly enlarge DRIVE's requirement for computer resources.

PROBLEMS WITH INTERCHANGEABLE AND SUBSTITUTABLE (I&S) LRUS

The Ogden prototype does not deal with the "I&S problem," but ultimately DRIVE should. Because of frequent engineering changes, the Air Force may have several versions of a particular LRU in its inventory. For each kind of LRU, there is a most preferred or latest version, which is called the *subgroup master*. One set of problems is knowing which versions can be used by a particular base, and this depends on having aircraft configuration data, which do not exist. Another aspect is that older versions can often be modified, and modifying is one of the depot's responsibilities. For the Ogden prototype, data for an I&S group is "rolled up," and this version of DRIVE pretends that only subgroup masters exist, leaving it to people in the system to sort things out. Because the Ogden prototype does not deal with configuration data, there is a rule that an item should not be sent to a base unless the depot has a backordered requisition for the item. This is to prevent sending things to places that have no use for them. (This also partly mitigates errors arising from having to use worldwide application fractions rather than base-specific fractions.) The unfortunate result is that DRIVE's allocations are constrained by the stock levels that generate the backorders, and those stock levels may be inconsistent with the aircraft availability goals specified to DRIVE.

INPUT DATA FROM THE PREPROCESSOR

The list below indicates the data from the preprocessor given to the DRINP program.

Bases

Base Identification

- Supply account number (SRAN).
- Organization (e.g., 31TFW).
- Base's location (e.g., Homestead, Florida).
- Base-specific shipping time in days.

Base Flying Program and Resources

- Number of possessed aircraft (PAA) by aircraft (A/C) series.
- Peacetime flying program in hours per month by A/C series.
- Wartime flying program, hours in 30 days by A/C series.
- Yes/no indicator of LRU repair capability in peacetime.
- Yes/no indicator of LRU repair capability in wartime.

Item Identification (for each LRU and SRU)

- National stock number (NSN).
- Description (terse).
- Part number.
- Control number.
- Work unit code.
- Identification of the item manager.
- Identification of the equipment specialist.

LRUs

LRU Usage, Failure, and Repair Data

- Number of copies in aircraft by A/C series (QPA).
- Fraction of aircraft using the LRU by A/C series (FAP).

- Removals at bases per 100 hours of operation (OIMDR).
- Base repair fraction (fraction of removals repaired at the base).
- Test stand used for repair (one of four).
- Standard hours for repair.

Status of LRUs at the Depot

- Stock of serviceable LRUs.
- Repairable carcasses.
- Number already inducted.
- SRUs missing from each diagnosed LRU in repair.

LRU Status at Each Base

- Serviceable LRUs on hand.
- Serviceable LRUs on the way to the base.
- Unserviceable LRUs on the way to the depot.
- Number of LRUs in base repair.
- Base-specific fraction of aircraft using the LRU, if available (FAP).
- Number of LRUs missing from aircraft.
- Authorized number of LRUs in the base's war reserve.

SRUs

SRU Usage, Failure, and Repair Data

- Parent LRU.
- Number of copies in the parent LRU (QPA).
- Removals at bases per 100 hours of operation (OIMDR).
- Depot replacement factor (probability of need).
- Repair shop (one of three).
- Standard hours for repair.

Status of SRUs at the Depot

- Stock of serviceable SRUs in depot stock.
- Stock of SRUs in the LRU shop (DMSC).

- Repairable carcasses.
- Number already inducted.

SRU Status at Each Base

- Serviceable SRUs on hand.
- SRUs missing from LRUs.
- Serviceable SRUs on the way to the base.
- Unserviceable SRUs on the way to the depot.

4. SHOP CAPACITY AND PRIORITY LISTS

This section discusses steps 4 and 5 of the priority-setting process as implemented in the DRIVE prototype at Ogden: adjusting priorities to match shop capacity and making the priority lists. The former includes specifying SRUs that should be available in the depot maintenance support center (DMSC) for anticipated LRU repairs in the subsequent production period.

STEP 4—ADJUSTING FOR CAPACITY

As noted in Section 2, the LSRU program that calculates priorities does not attempt to deal with repair shop capacity, and its decisions of how far to go in generating repair and distribution actions for the LRUs are determined mainly by a user-specified minimal sort value. The stopping value should be set low enough that generous lists of repair and distribution actions are produced, but not so low as to waste computer resources. The "line-drawing"[1] program, described here, is used in an interactive fashion to select enough of the repair actions to keep the shops busy during the coming production period. At Ogden, this is two weeks.[2] At its simplest, line drawing is a matter of running down the merged list of repair actions produced by the prioritization algorithm, keeping a running total of the hours implied by the specified repairs until a desired total number of hours is accumulated. The line-drawing program can be used in more complex ways, however.

The program operates in three phases. In the first phase, it loads data about the LRUs and SRUs (identifying information, their test stands or repair shops, and repair times) and data relating to the repair priorities that were computed by the LSRU program.[3] The sec-

---

[1]The term *line-drawing* comes from an image of drawing a line across a list of repair actions showing how far down the list the shops should go.

[2]The production period should not be confused with DRIVE's planning horizons, which affect only the probability distributions of items returned from bases to the depot for repair. The choice of two weeks is a compromise. We wanted DRIVE to be run frequently for overall responsiveness. On the other hand, we wanted the production period to be long relative to the time lag between the date of the asset position data and the start of the production period. Implications of this time lag are discussed below when we describe priority lists.

[3]These are the LSRUNAME.DAT, DRIVOUT.DAT, and GAME.DAT files described in Appendix C. LSRUNAME.DAT has the identifying information, DRIVOUT.DAT

ond phase is manipulation by the user to achieve the desired shop load. In the third phase, shortened versions of the files produced by the prioritization algorithm to indicate repair and distribution priorities are written.[4] Also during the third phase, calculations are carried out to invoke the notion of *proactive SRU repair*, which designates the repair of additional SRUs during the coming production period to satisfy requirements for SRUs that are likely to be needed by the depot LRU repair activity in the following production period.

The interactive operation of the line-drawing program is illustrated in Figures 4.1 through 4.6. Figure 4.1 reproduces the computer screen just after the files have been read. The AIS shop (for avionics intermediate shop) has four types of test stands designated by CI, DI, PP, and RF. The top line in the display labels columns relating to the four kinds of stands and the total. The second line, labeled "Most Hours," indicates the total number of standard hours on the corresponding test stand that would be used if all the repairs indicated by the records in the DRIVOUT.DAT file were carried out.

The line labeled "Manipulate AIS" offers choices for the user. It operates like a simple menu. (In Figures 4.1 through 4.6, screens are reproduced with menu items in bold type.) The currently selected entry appears in reverse video (here indicated by underlining). The user changes the indicated item with the left and right arrow keys,

```
AIS Stand         CI       DI       PP       RF       Total
Most Hours        3660     3128     3744     3881     14413
Manipulate AIS: Hours    Hr_Constraints Probs    Sort_Vals Done

                  CI       DI       PP       RF       Total
AIS Stand         0        0        0        0        0
Analog            0        0        0        0        0
Digital           0        0        0        0        0
Microwave         0        0        0        0        0
```

Figure 4.1—Starting Screen for LINDRAW Program

contains information specifying repair actions, and GAME.DAT contains data that permit the line drawing program to deal with probabilities.

[4]These are DRIVOUT.DAT and ITEMMGR.DAT in Appendix C.

and the selection is activated by pressing the *Enter* key. The first four choices are various ways of selecting repair/distribution actions, although normally only the first two are used. The program allows the user to return to this kind of selection as often as desired so that it is possible to try any number of approaches to loading the shop. The last choice, "Done," is picked when the user has made final adjustments and wants to go on to the third phase of producing output files.

Below the menu is a four-by-five matrix that shows the numbers of hours by test stand and the total. The top row is for the LRU shop's stands. The next three rows relate to the three supporting SRU shops. An element in that part of the matrix is the number of hours in the indicated SRU shop taken up by SRUs that go in LRUs that are repaired with the AIS test stand in the corresponding column. Thus, for example, the intersection of the "Analog" row and "CI" column is the number of hours for SRUs repaired in the Analog Shop and belonging to LRUs that are repaired on the CI stand. The matrix is filled with zeros because we have yet to specify any production.

To see how the line-drawing program might be used, suppose that we wish to develop a production plan that calls for 3000 total standard hours for the four AIS test stands, but none of the stands should have more than 800 hours. (The 3000 hours are likely to be derived from a budget constraint and the 800-hour limits reflect physical capacity.) We can proceed by starting with an unconstrained plan for 3000 total hours and then apply the constraints. To begin, work the arrow keys to highlight "Hours" on the Manipulate AIS menu and press *Enter*. This results in the screen reproduced in Figure 4.2. The menu disappears, to be replaced by a new one labeled "Choose." Also, the label "Hour limit" appears because the program knows we are going to be specifying hours rather than probabilities or sort values. The Choose menu asks us for which stand we intend to designate a number of hours, or for the total to be specified. "Total" is chosen and the *Enter* key is pressed. The computer responds by removing the Choose menu and indicating a field in reverse video over the Total column for the number of hours to be entered. We type "3000" and press the *Enter* key.

At this point, the computer figuratively runs down the list of repair priorities until the total number of hours in the AIS shop reaches 3000 and produces the display shown in Figure 4.3. (Figure 4.3 actually shows two screens, but the user can have the computer alternate between them.) The hours matrix is filled in, and we see that the

AIS Stand	CI	DI	PP	RF	Total
Most Hours	3660	3128	3744	3881	14413
Choose:	**CI**	**DI**	**PP**	**RF**	**Total**
		Hour limit:			
	CI	DI	PP	RF	Total
AIS Stand	0	0	0	0	0
Analog	0	0	0	0	0
Digital	0	0	0	0	0
Microwave	0	0	0	0	0

Figure 4.2—After Selecting Hours

3000 hours would be made up of 795 hours on the CI stands, 524 hours on the DI stands, 884 hours on the PP stands, and 807 hours on the RF stands. The total of 3010 is greater than the 3000 hours specified because the last repair action to get up to 3000 hours brought the total to 3010. Note that this plan calls for only 213 standard hours of repair in the microwave shop. This is because the original data showed fairly rich stocks of that shop's SRUs.

Now there is a second matrix of repair hours with the indication that it is "Repairs for the next period." The numbers there were obtained by running further down the priority list until 6000 standard hours of LRU repairs were reached. The additional 3000 hours are taken to be representative of the workload in the following production period and are the basis for DRIVE's proactive SRU repair logic.

The lower half of Figure 4.3 gives information about the individual LRUs, of which there are 42 in this example. Each LRU is described by five lines. The first five rows are about the first 12 LRUs, etc. For an LRU, the first two lines are identification. The top line indicates the test stand and a number, 1 through 42, which comes from the order in which the LRUs were considered by the prioritization program. The second line is the last four digits of the LRU's National Stock Number (NSN). The third line, labeled "Prob," is the probability that all bases meet their availability goals with respect to the LRU in question. The rows indicated by "S.V." show the sort values asso-

AIS Stand	CI	DI	PP	RF	Total
Most Hours	3660	3128	3744	3881	14413

Manipulate AIS: **Hours Hr_Constraints Probs Sort_Vals Done**

Hour limit:					**3000**
	CI	DI	PP	RF	Total
AIS Stand	795	524	884	807	3010
Analog	388	422	300	40	1151
Digital	243	16	243	0	502
Microwave	0	0	0	213	213

Repairs for next period --

AIS Stand	766	800	1115	318	2999
Analog	561	455	259	139	1414
Digital	172	179	524	29	904
Microwave	0	0	0	443	443

	CI 1	RF 2	DI 3	RF 4	RF 5	RF 6	RF 7	DI 8	PP 9	RF10	DI11	PP12
	3976	2256	6872	2962	2963	2965	2966	9955	6494	4630	7430	2990
Prob	.0156	.0000	.1964	.0000	.0000	.0000	.0000	.0009	.0088	.0001	.0007	.0059
S.V.	.0200	.0113	.0000	.0114	.0000	.0157	1.690	.0161	.0188	.0121	.0121	.0132
Qty	6	3	0	9	0	9	8	2	3	0	5	0
	CI13	PP14	PP15	DI16	PP17	PP18	PP19	PP20	PP21	RF22	DI23	DI24
	3829	3858	3859	0543	7914	1499	6879	4855	0203	1313	3945	4833
Prob	.0640	.0216	.0529	.0022	.0175	.0006	.0005	.0000	.1098	.0234	.0000	.0000
S.V.	.0115	.0000	.0000	.0185	.0117	.0122	.0120	.0141	.0140	.0435	.0127	.0113
Qty	5	0	0	1	4	16	13	3	2	10	17	6
	CI25	PP26	PP27	CI28	CI29	CI30	PP31	CI32	PP33	CI34	PP35	CI36
	0712	8924	3978	3533	6645	7817	1018	0046	1859	7834	7835	3160
Prob	1.00	.0079	.0041	.0000	.0000	.3271	.0002	.0277	.0141	.1575	.0002	.0096
S.V.	.0000	.0121	.0111	.0126	.0112	.0172	.0116	.0133	.0116	.0115	.0201	.0111
Qty	0	5	5	15	6	2	6	3	1	9	5	11
	CI37	CI38	CI39	CI40	CI41	CI42						
	7445	1592	0136	3851	6374	6771						
Prob	.0487	.0247	.0016	.0274	.6618	.3374						
S.V.	.0114	.0000	.0111	.0110	.0000	.0000						
Qty	10	0	4	3	0	0						

Press a key to return from this display:

Figure 4.3—After Choosing Total and Entering 3000 Hours

ciated with the last repair actions involving the LRUs. (An LRU with no repair actions in plan shows a sort value of zero.) The fifth line, labeled "Qty," is the number of LRUs to be repaired according to the plan.

We now proceed to invoke the 800-hour constraint on the individual AIS test stands. For each of the four test stands, we choose "Hours" from the Manipulate AIS menu, select a test stand from the Choose menu (shown in Figure 4.2) and enter 800 hours. Figure 4.4 shows what the displays look like after these steps have been taken. The data in the displays represent a plan where all stands are scheduled for 800 hours, and the total hours across stands for the resulting repair actions is 3228. While we may not be interested in this plan, what is important is that the user's inputs—3000 hours total and no more than 800 hours on any single type of test stand—are entered and show on the line labeled "Hour limit." The final step is to select "Hr_Constraints" from the Manipulate AIS menu. The results are shown in Figure 4.5.[5]

Having achieved a plan according to the given constraints, the user picks "Done" from the Manipulate AIS menu. The screen clears and, as illustrated by Figure 4.6, the user is asked a series of yes-no questions relating to the desired outputs, which may include shortened lists of repair and distribution priorities and a summary showing the number of each item to be repaired. Finally, the user is asked if he wants to go back to phase 2 ("Again?").[6]

Our example showed that a production plan can be calculated to put hour limits on each type of AIS stand and the total. But one may also choose simply to specify the numbers of hours for the four kinds of test stands or the total across all AIS stands. This particular version of the line drawing program does not offer a means for independently controlling hours in the SRU shops. That capability, however, is present in a less elaborate program written at AFLC headquarters.

---

[5]One may notice that the 800-hour constraint is exceeded for the DI stand in the next period portion of the display. The reason is that the computer program interpreted the limits as 800 hours for one period and 1600 hours for two periods, rather than 800 hours in each period.

[6]The output files are given unique names, e.g., DRIVOUT.1, DRIVOUT.2, etc., so that all the work will be preserved.

AIS Stand	CI	DI	PP	RF	Total
Most Hours	3660	3128	3744	3881	14413

Manipulate AIS: **Hours** Hr_Constraints Probs Sort_Vals Done

	CI	DI	PP	RF	Total
Hour limit:	800	800	800	800	3000
AIS Stand	803	815	806	803	3228
Analog	388	600	254	13	1255
Digital	251	54	206	0	511
Microwave	0	0	0	158	158

Repairs for next period --

	CI	DI	PP	RF	Total
AIS Stand	811	790	794	803	3198
Analog	633	420	166	301	1519
Digital	175	184	304	58	720
Microwave	0	0	0	1082	1082

	CI 1	RF 2	DI 3	RF 4	RF 5	RF 6	RF 7	DI 8	PP 9	RF10	DI11	PP12
	3976	2256	6872	·2962	2963	2965	2966	9955	6494	4630	7430	2990
Prob	.0156	.0000	.1964	.0000	.0000	.0000	.0000	.0020	.0088	.0001	.0017	.0059
S.V.	.0200	1.737	.0000	1.713	.0000	1.739	1.690	.0102	.0188	.0000	.0092	.0132
Qty	6	3	0	9	0	9	8	4	3	0	9	0
	CI13	PP14	PP15	DI16	PP17	PP18	PP19	PP20	PP21	RF22	DI23	DI24
	3829	3858	3859	0543	7914	1499	6879	4855	0203	1313	3945	4833
Prob	.0640	.0216	.0529	.0031	.0116	.0006	.0004	.0000	.1098	.0196	.0001	.0001
S.V.	.0115	.0000	.0000	.0091	.0161	.0122	.0123	.0141	.0140	.0449	.0093	.0093
Qty	5	0	0	2	3	16	12	3	2	9	23	9
	CI25	PP26	PP27	CI28	CI29	CI30	PP31	CI32	PP33	CI34	PP35	CI36
	0712	8924	3978	3533	6645	7817	1018	0046	1859	7834	7835	3160
Prob	1.00	.0079	.0029	.0000	.0000	.3271	.0001	.0277	.0118	.1575	.0002	.0111
S.V.	.0000	.0121	.0122	.0126	.0112	.0172	.0124	.0133	.0000	.0115	.0201	.0110
Qty	0	5	5	15	6	2	4	3	0	9	5	12
	CI37	CI38	CI39	CI40	CI41	CI42						
	7445	1592	0136	3851	6374	6771						
Prob	.0487	.0247	.0016	.0274	.6618	.3374						
S.V.	.0114	.0000	.0111	.0110	.0000	.0000						
Qty	10	0	4	3	0	0						

Press a key to return from this display:

Figure 4.4—After Setting Hours for Each LRU Test Stand Type to 800

AIS Stand	CI	DI	PP	RF	Total
Most Hours	3660	3128	3744	3881	14413

Manipulate AIS: **Hours** **Hr_Constraints** **Probs** **Sort_Vals** **Done**

Hour limit:	800	800	800	800	3000
	CI	DI	PP	RF	Total
AIS Stand	803	609	806	803	3022
Analog	388	469	254	13	1125
Digital	251	46	206	0	503
Microwave	0	0	0	158	158

Repairs for next period --

AIS Stand	811	909	794	482	2996
Analog	633	481	166	212	1492
Digital	175	192	304	36	706
Microwave	0	0	0	683	683

	CI 1	RF 2	DI 3	RF 4	RF 5	RF 6	RF 7	DI 8	PP 9	RF10	DI11	PP12
	3976	2256	6872	2962	2963	2965	2966	9955	6494	4630	7430	2990
Prob	.0156	.0000	.1964	.0000	.0000	.0000	.0000	.0020	.0088	.0001	.0009	.0059
S.V.	.0200	1.737	.0000	1.713	.0000	1.739	1.690	.0102	.0188	.0000	.0104	.0132
Qty	6	3	0	9	0	9	8	4	3	0	6	0
	CI13	PP14	PP15	DI16	PP17	PP18	PP19	PP20	PP21	RF22	DI23	DI24
	3829	3858	3859	0543	7914	1499	6879	4855	0203	1313	3945	4833
Prob	.0640	.0216	.0529	.0022	.0116	.0006	.0004	.0000	.1098	.0196	.0000	.0000
S.V.	.0115	.0000	.0000	.0185	.0161	.0122	.0123	.0141	.0140	.0449	.0127	.0100
Qty	5	0	0	1	3	16	12	3	2	9	17	7
	CI25	PP26	PP27	CI28	CI29	CI30	PP31	CI32	PP33	CI34	PP35	CI36
	0712	8924	3978	3533	6645	7817	1018	0046	1859	7834	7835	3160
Prob	1.00	.0079	.0029	.0000	.0000	.3271	.0001	.0277	.0118	.1575	.0002	.0111
S.V.	.0000	.0121	.0122	.0126	.0112	.0172	.0124	.0133	.0000	.0115	.0201	.0110
Qty	0	5	5	15	6	2	4	3	0	9	5	12
	CI37	CI38	CI39	CI40	CI41	CI42						
	7445	1592	0136	3851	6374	6771						
Prob	.0487	.0247	.0016	.0274	.6618	.3374						
S.V.	.0114	.0000	.0111	.0110	.0000	.0000						
Qty	10	0	4	3	0	0						

Press a key to return from this display:

Figure 4.5—After Applying Hour Constraints

```
Shall I write a new DRIVOUT file? (y or n): y

Want lists of items and quantities by shop? (y or n): y
I have to read some of DRIVOUT.DAT again.
....
I'm done after reading 410 lines from DRIVOUT.DAT
and writing 346 lines to DRIVOUT.1
I wrote SHOPLIST.1.

Shall I write a new IM file? (y or n): y
I wrote ITEMMGR.1

Again? (y or n):n
```

Figure 4.6—Choose "Done" and Respond to Choices of Outputs

PROACTIVE SRU REPAIR

The probability of success in executing a repair plan for LRUs would be enhanced if the required serviceable SRUs were already available. DRIVE specifies repair actions for SRUs in the upcoming production period to provide a stock of SRUs for repairing LRUs in the following period. This is accomplished in the following way. We have seen in the example that the line-drawing program projects LRU repairs for a subsequent production period by doubling the single-period repair-hour limits. When the line-drawing program writes out modified files that will be used for making repair lists in step 5, it includes the allocations of SRUs and necessary repair actions to support LRU repairs in the second period. The priority lists will indicate period 1 or period 2 to distinguish among SRUs intended for the upcoming production period or the subsequent one.

STEP 5—PRIORITY LISTS

The final processing step is to produce priority lists from the outputs of the line-drawing program. At Ogden, a separate repair priority list is made for each of the four AIS shop test stand types and for each of

the three SRU shops. Distribution lists are made for each item manager.

Figure 4.7 shows the beginning of the priority list for the DI test stand made from the repair priority file produced by the line-drawing exercise. The column headings are fairly self-explanatory. The item is identified by its national stock number and terse nomenclature. The item manager and equipment specialist are identified by codes,

THE D.I. SHOP 24-JUN-91

SEQ	REPAIR TYPE	MASTER NSN	ITEM DESCR	IM	ES	PER IOD	BASE	CUM RPR	STD HRS	TOT HRS
1	AWP	5841-01-096-3945WF	REO DISP	HA6	HM	1	HANC	1	12.2	12
2	AWP	5841-01-096-3945WF	REO DISP	HA6	HM	1	HANC	2	12.2	24
3	AWP	5841-01-096-3945WF	REO DISP	HA6	HM	1	BURL	3	12.2	37
4	AWP	5841-01-096-3945WF	REO DISP	HA6	HM	1	HANC	4	12.2	49
5	AWP	5841-01-096-3945WF	REO DISP	HA6	HM	1	BURL	5	12.2	61
6	AWP	5841-01-096-4833WF	REO EU	HA6	HM	1	HANC	1	26.1	87
7	AWP	5841-01-096-3945WF	REO DISP	HA6	HM	1	JACK	6	12.2	99
8	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	HANC	7	12.2	111
9	AWP	1270-01-199-7430WF	HUD PDU	HA6	HL	1	CAPI	1	20.3	132
10	AWP	5841-01-096-3945WF	REO DISP	HA6	HM	1	BURL	8	12.2	144
11	AWP	1270-01-122-9955WF	HUD ELECT	HWP	HL	1	HANC	1	19.5	163
12	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	EGLI	9	12.2	176
13	AWP	5841-01-096-4833WF	REO EU	HA6	HM	1	ELLI	2	26.1	202
14	IND	1270-01-122-9955WF	HUD ELECT	HWP	HL	1	JACK	2	19.5	221
15	AWP	1270-01-199-7430WF	HUD PDU	HA6	HL	1	EGLI	2	20.3	242
16	AWP	5841-01-096-4833WF	REO EU	HA6	HM	1	GREA	3	26.1	268
17	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	JACK	10	12.2	280
18	AWP	1270-01-274-0543WF	HUD ELEC U	HWP	HL	1	KING	1	19.5	299
19	IND	5841-01-096-4833WF	REO EU	HA6	HM	1	JACK	4	26.1	326
20	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	EDWA	11	12.2	338
21	OWO	1270-01-199-7430WF	HUD PDU	HA6	HL	1	ATLA	3	20.3	358
22	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	KING	12	12.2	370
23	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	NIAG	13	12.2	382
24	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	HANC	14	12.2	395
25	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	EGLI	15	12.2	407
26	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	JACK	16	12.2	419
27	IND	5841-01-096-3945WF	REO DISP	HA6	HM	1	BURL	17	12.2	431
28	OWO	1270-01-199-7430WF	HUD PDU	HA6	HL	1	DANN	4	20.3	452
29	OWO	1270-01-199-7430WF	HUD PDU	HA6	HL	1	BURL	5	20.3	472
30	IND	5841-01-096-4833WF	REO EU	HA6	HM	1	TUCS	5	26.1	498
31	IND	5841-01-096-4833WF	REO EU	HA6	HM	1	HANC	6	26.1	524
32	OWO	1270-01-199-7430WF	HUD PDU	HA6	HL	1	KING	6	20.3	544
33	OWO	1270-01-122-9955WF	HUD ELECT	HWP	HL	1	GREA	3	19.5	564
34	OWO	1270-01-122-9955WF	HUD ELECT	HWP	HL	1	ATLA	4	19.5	583
35	IND	5841-01-096-4833WF	REO EU	HA6	HM	1	EGLI	7	26.1	609
36	IND	5841-01-096-4833WF	REO EU	HA6	HM	2	JACK	8	26.1	636
37	IND	5841-01-096-3945WF	REO DISP	HA6	HM	2	KING	18	12.2	648
. . .										
87	IND	5841-01-096-4833WF	REO EU	HA6	HM	2	NIAG	17	26.1	1518

Figure 4.7—Priority List for the DI Test Stand

and an abbreviation is given for the name of the base for which the item is being repaired.

An entry in the column headed by "CUM RPR," for cumulative repairs, gives the number of appearances of an LRU on the list down through the line. For example, line number 37 is for the 18th REO DISPLAY on the list. The "STD HRS" column contains the standard repair times for the individual items, and the next column, "TOT HRS," is the running cumulative sum of standard repair times over all items on the list so far.

On the left side, an entry in the column headed by "REPAIR TYPE" contains one of three indications: "AWP" for LRUs in that condition, "OWO" for LRUs that have already been inducted but are not known to DRIVE to be in AWP status, and "IND" to show that the item would have to be inducted into the shop. The important distinction is between LRUs that are already in the shop versus new inductions. This helps the shop plan for inductions but also serves to mitigate confusion caused by the time lag between the running of DRIVE and the start of the production period. If line drawing is based on a production period of two weeks, the two weeks should logically begin at the time when the data on shop status were current. These data, however, are several days old by the time the production period actually starts, and it is expected that some of the items on the list would have been repaired by the start of the period.[7] If eliminating the time lag is impossible, a solution would be to have DRIVE consider the production period to have a length equal to the sum of the actual period plus the time lag. If data were available on what items had been produced during the lag, corresponding lines could be deleted from the top of the list.

Production lists also include period 1 and period 2 repairs as described in the discussion of proactive SRU repair. Period 2 LRUs are included to give the shop some advance warning and to provide the shop with more work, since they often must skip items for lack of parts or carcasses. Notice that the repair on line 35 of Figure 4.7 is the last one with an indication of period 1. The cumulative hours against that LRU repair is 609, which agrees with the DI shop hours in Figure 4.5.

[7]In the extreme case, suppose the production period were equal to the time lag. Then the production list would contain only repairs that DRIVE would have hoped had already been accomplished and nothing about future actions.

Figure 4.8 shows the distribution priorities for two of the items under the management of item manager HA6. The notion is that the item manager works from the top of the list for each item as assets become available. The first item on HA6's list is the 3945 REO Display LRU, and we see the distribution priorities for the 17 units called for in Figure 4.5 (in Figure 4.5, it is DI23, near the end of the second group of LRUs). The second item is an SRU. DRIVE is suggesting that the first two and the ninth go to bases and the rest to the AIS shop. The period indicator switches to 2 starting with the tenth SRU, indicating that these SRUs are the ones that we would like to have available to the AIS shop in anticipation of needs in the next period.

D I S T R I B U T I O N   P R I O R I T I E S   24-JUN-91
OGDEN ALC F-16 AIS & SRU SHOPS

ITEM MANAGER HA6

PRTY	MASTER NSN	ITEM	SUPPLY ACCT	ORG	BASE NAME	PER IOD
1	5841-01-096-3945WF	REO DISP	FB6451	158TFG	BURLINGTON VT	1
2			FB6324	174TFW	HANCOCK NY	1
3			FB6324	174TFW	HANCOCK NY	1
4			FB6451	158TFG	BURLINGTON VT	1
5			FB6324	174TFW	HANCOCK NY	1
6			FB6451	158TFG	BURLINGTON VT	1
7			FB6091	FIS 159	JACKSONVILLE	1
8			FB6324	174TFW	HANCOCK NY	1
9			FB6451	158TFG	BURLINGTON VT	1
10			FB2823	ADTCE	EGLIN AFB FL	1
11			FB6091	FIS 159	JACKSONVILLE	1
12			FB2805	AFFTC	EDWARDS AFB C	1
13			FB6372	114TF	KINGSLEY FIEL	1
14			FB6321	107FIG	NIAGARA FALLS	1
15			FB6324	174TFW	HANCOCK NY	1
16			FB2823	ADTCE	EGLIN AFB FL	1
17			FB6091	FIS 159	JACKSONVILLE	1
18			FB6451	158TFG	BURLINGTON VT	2
1	5960-01-084-4987WF	CRT ASSY	FB6451	158TFG	BURLINGTON VT	1
2			FB6123	183 TFG	CAPITAL IL	1
3			FB2029		OGDEN, UT	1
4			FB2029		OGDEN, UT	1
5			FB2029		OGDEN, UT	1
6			FB2029		OGDEN, UT	1
7			FB2029		OGDEN, UT	1
8			FB2029		OGDEN, UT	1
9			FB6123	183 TFG	CAPITAL IL	1
10			FB2029		OGDEN, UT	2
11			FB2029		OGDEN; UT	2
12			FB2029		OGDEN, UT	2
13			FB2029		OGDEN, UT	2
14			FB2029		OGDEN, UT	2
15			FB2029		OGDEN, UT	2
16			FB2029		OGDEN, UT	2
17			FB2029		OGDEN, UT	2
18			FB2029		OGDEN, UT	2
19			FB2029		OGDEN, UT	2
20			FB2029		OGDEN, UT	2
21			FB2029		OGDEN, UT	2

Figure 4.8—Distribution Priorities for IM HA6

5. DDSP: THE DRIVE DECISION SUPPORT PROGRAM

The DRIVE Decision Support Program replays sequences of repair and allocation decisions made by the LSRU program. Our original motivation was to develop an aid for explaining DRIVE's logic and behavior. As the DDSP has evolved, however, we have found that it provides a great deal of diagnostic information and furnishes understanding available in no other way about the status and problems associated with the various LRU families.

The inputs to the DDSP are the files produced by the DRINP program in step 2 plus a special file written by the prioritization program in step 3. The latter file contains a record for every repair and allocation action selected by the marginal analysis procedure. The remainder of this section describes the DDSP through a series of figures reproduced from computer screens displayed by the program.

The user is first presented with a screen that identifies the set of LRUs, and he is asked to choose one. Such a screen is reproduced in Figure 5.1, where the user chooses LRU number 12. Based on that choice, the user is shown a display called the "main screen." Examples of the main screen at various points in stepping through the allocations for the selected LRU are shown in Figures 5.3, 5.4, and 5.9. The usual response by the user when the main screen is showing is to press the *Enter* key, first to reveal what the next allocation will be and again to have the display updated accordingly. But there are other options that the user may select by pressing various keys instead of *Enter*.

Figure 5.2 shows the help display that one gets by pressing the *h* key. It lists the other special keys and gives a brief description of what they do. The *d*, *r*, and *s* options, respectively, produce tabular displays of items distributed to bases, the repairs made so far, and the bases' asset positions. The *g* key brings up a bar graph that relates LRUs to expected demands at the bases. All of these are illustrated in the figures. The *f*, *l*, and *p* keys offer various ways of capturing displays in files or on printers. The *a* key causes the DDSP to run through all remaining allocations for the LRU family, and *q* tells DDSP not to process any more transactions. When the action of the *a* key is finished or the *q* key has been pressed, all the display and capturing options are available until the user presses *q* again to indicate

```
[ 1] 1270-01-045-3976WF  FIRE COMP      [18] 1290-01-080-0203WF  CRIU 75DE0
[ 2] 1270-01-093-2174WF  ANTENNA RA     [19] 5841-01-096-3945WF  DISP 74EA0
[ 3] 1270-01-093-2256WF  RADAR XMTR     [20] 5841-01-096-4833WF  RDR E74EB0
[ 4] 1270-01-094-6872WF  RCP  74AH0     [21] 5999-01-080-3978WF  JRIU 75DD0
[ 5] 1270-01-102-2962WF  LOW PWR RF     [22] 6605-01-046-3533WF  FC NAV PAN
[ 6] 1270-01-102-2963WF  LOW PWR RF     [23] 6605-01-087-6645WF  INU  74DA0
[ 7] 1270-01-102-2965WF  LOW PWR RF     [24] 6610-01-039-7817WF  ACCELER AS
[ 8] 1270-01-102-2966WF  LOW PWR RF     [25] 6610-01-089-1018WF  COMPUTR CA
[ 9] 1270-01-122-9955WF  HUD ELECT      [26] 6610-01-123-0046WF  ECA  14FB0
[10] 1270-01-133-6494WF  DIG SIG PR     [27] 6615-01-042-7834WF  GYRO
[11] 1270-01-199-7430WF  HUD PDU        [28] 6615-01-042-7835WF  PNE SENSOR
[12] 1270-01-209-9982WF  COMPUTER       [29] 6615-01-127-3160WF  PANEL
[13] 1280-01-109-1499WF  MRIU  75DB     [30] 6615-01-129-7445WF  PANEL TRIM
[14] 1280-01-121-6879WF  SCP 75DA0      [31] 6615-01-161-1592WF  FLT CTL CO
[15] 1280-01-224-8924WF  XCIU           [32] 6615-01-172-0136WF  FLCC
[16] 1280-01-262-0461WF  CIU            [33] 6615-01-220-3851WF  FL CTL CTR
[17] 1280-01-280-4855WF  CIU            [34] 6625-01-114-6771WF  RECORD ASY

Which: 12
```

Figure 5.1—DDSP: Screen for Choosing an LRU

```
ACTIONS AT Show next allocation: or Update Status: PROMPTS

Enter  move from Show to Update or Update to Show
    a  automatically move thru to last transaction
    c  change colors
    d  show items distributed to bases
    f  add image of screen to file ddsp.dat
    g  show graph
    r  show repairs made so far
    s  show stock
    q  quit for this LRU


WITH GRAPH DISPLAYED

    c  change colors
    l  capture graph image in a postscript file Lnn.PIC
    p  print graph image on your local Epson-like printer

You may scroll bases with <-- and --> at any time

Press Enter to return to main screen
```

Figure 5.2—Help Screen

that he is done with the LRU family. The *c* option is not illustrated by the figures; it allows one to choose colors for the various elements of the graphical display and two colors for the main screen.

MAIN SCREEN

Figure 5.3 reproduces the main screen immediately after LRU number 12 was chosen. The top line indicates the LRU. Below that and above the continuous line across the figure are columns relating to the bases. The bases are numbered 1 through 17, and the line below the numbers contains three-letter abbreviations for the base names. The line labeled "PrOK" gives the bases' probabilities of meeting their availability goals for this LRU. The line indicated by WRM contains the bases' numbers of authorized LRUs in their WRSKs. DRIVE does not use these numbers in any way, but it is interesting to see them

```
              LRU NSN 1270-01-209-9982WF  COMPUTER   GAME.DAT [12]
        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
      MOO HOM TIN MCE HIL GRE HAN FOR CAP ATL KEL WRI FAR AND SEL FRE MCC  -->
PrOK .41 .36 .48 .39 .53 .06 .18 .64 .07 .06 .54 .58 .49 .89 .69 .45 .34

WRM     0  14   3   0  13   1   2   3   0   1   0   0   0   2   0   0   0
Dmnd   16  14 5.2 4.9 4.8 4.0 4.0 4.0 3.9 3.9 3.8 3.4 3.1 1.6 1.2 1.0 1.1
Stck    2   1   0   0   1   0   1   1   0   0   0   0   0   0   0   0   0
------------------------------------------------------------------------------
SRU     0   1   2   3   4   5   6   7   8   9  10  11
QPA     1   1   1   1   1   1   1   1   1   1   1   1

                              AWP LRUs
Stck
Hole

         DEPOT              7 AWP LRUs
Stock   3   3   0   6   0   1   0   0   0   0   4   2
MIC S       0   0   2   0   1   0   2   0   1   1   0
Holes       0   2   0   0   0   0   0   5   1   0   0
Reps   12  31  65   9  21  21  34 140  38   7  11  42

------------------------------------------------------------------------------
Show next allocation:    Update status:     |Xactn Steps Hours   Prob SortVal
                                            |    0     0     0 0.0000 0.00000
```

Figure 5.3—Main Screen Before Allocations

here. For the bases, "Dmnd" (demand) reflects the expected numbers of LRUs that the bases will remove from aircraft and send to the depot during their horizons, and "Stck" shows the current numbers of spare serviceable LRUs that the bases have in stock. The bases are ordered according to their entries in the "Dmnd" row, from high to low. Since there is room for only 17 bases, the left and right arrow keys can be used to scroll across the bases. (This is what the little arrow near the top right is meant to suggest.)

The next part of the display between the two solid lines is a set of columns relating to the LRU and SRUs. The line headed by SRU simply shows numbers for labeling the SRUs, with SRU 0 being the LRU. The line below that, labeled "QPA," is the number of copies of the LRU in the aircraft and of the SRUs in the LRU. The three lines containing the label "AWP LRUs" and the "Stck" and "Hole" rows have no data yet. They are there to show the asset position of the base that gets the current allocation, but the first allocation decision has yet to be revealed.

The last five lines above the lower solid line indicate the status of items at the depot. There are currently seven LRUs that have been diagnosed and are AWP for specific SRUs. The numbers of missing SRUs in the seven AWP LRUs are shown in the row labeled Holes. The lines above the holes show stocks of serviceable items in ordinary depot stock and in the LRU shop (maintenance inventory center [MIC], now called the DMSC). Below Holes is a row indicating numbers of reparable carcasses. There is room for an additional row below the "Reps" line. When DRIVE elects to complete the repair of one of the depot's AWP LRUs, that space is used to indicate the number of various SRUs used to fix the LRU.

At the bottom of the display, below the solid line, is the user's control. The cursor is initially positioned at the right of "Show next allocation:" and the words appear in a different color from the rest of the display. When the user presses the *Enter* key, the line below will tell what item is to be sent to which base and whether it is to be from stock, inducted, or the completion of an LRU repair. The standard hours involved with the transaction is also written. An example of this information can be seen at the bottom of Figure 5.4. The asset position for the base receiving the item is filled in, as is also illustrated in Figure 5.4.

Also, in Figure 5.3 the cursor jumps to the right of the "Update status:" phrase, and that becomes highlighted. When the *Enter* key is pressed, the appropriate data in the display will be updated to reflect

```
                LRU NSN 1270-01-209-9982WF  COMPUTER   GAME.DAT [12]
        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
      MCO HOM TIN MCE HIL GRE HAN FOR CAP ATL KEL WRI FAR AND SEL FRE MCC  -->
PrOK .41 .36 .48 .50 .64 .51 .49 .64 .47 .51 .54 .69 .49 .89 .69 .75 .76

WRM     0  14   3   0  13   1   2   3   0   1   0   0   0   2   0   0   0
Dmnd   16  14 5.2 4.9 4.8 4.0 4.0 4.0 3.9 3.9 3.8 3.4 3.1 1.6 1.2 1.0 1.1
Stck    2   1   0   1   2   3   3   1   3   3   0   1   0   0   0   1   1
--------------------------------------------------------------------------
SRU     0   1   2   3   4   5   6   7   8   9  10  11
QPA     1   1   1   1   1   1   1   1   1   1   1   1

        JACKSONVILLE FL     1 AWP LRUs
Stck    0   0   0   0   0   4   0   0   0   0   0   0
Hole    0   0   0   0   0   0   0   0   1   0   0   0

        DEPOT               0 AWP LRUs
Stock   0   2   0   6   0   0   0   0   0   0   0   0
MIC S       0   0   1   0   0   0   1   0   0   0   0
Holes       0   0   0   0   0   0   0   0   0   0   0
Reps    8  31  61   9  20  20  33 138  31   7  11  42

--------------------------------------------------------------------------
Show next allocation:    Update status:     |Xactn Steps Hours   Prob SortVal
SRU  8 to base 23 (JAC) Induct Hours = 10.2 |  865    31   475 0.0000 0.00949
```

Figure 5.4—Main Screen After 31 Allocation Steps

all changes from the transaction. On the bottom right of the screen, the DDSP program keeps track of the original transaction number that the prioritization program (LSRU) assigned to the action, the number of steps gone through for this LRU, the total of the standard hours, the probability that all bases achieve their availability goals for the LRU, and the sort value associated with the current allocation.

DRIVE shows each allocation step in two stages to make it easier to see how the status is changed if the nature of the transaction is known first.

Figure 5.4 shows the state of affairs for this particular LRU after 31 allocation steps have been taken. Among other things, one can see that all 3 LRUs in stock at the depot have been distributed, the 7 AWP LRUs have been repaired, and because the number of LRU carcasses has gone from 12 to 8, 4 LRUs were inducted.

OTHER DISPLAYS

Figures 5.5 through 5.8 all relate to the status shown in Figure 5.4.

Repairs So Far

SRU	LRUs Finshd	LRUs Indctd	For Bases	Total
0	7	4		11
1	0	1	0	1
2	2	2	2	6
3	0	1	0	1
4	0	1	1	2
5	0	1	1	2
6	0	2	1	3
7	0	1	2	3
8	5	2	2	9
9	0	2	0	2
10	0	1	0	1
11	0	3	0	3

Press Enter to return to main screen:

Figure 5.5—Display Repairs

Repairs So Far

Figure 5.5 indicates items repaired and the use to which the repaired SRUs were put. The top line is for LRUs and indicates the 7 AWP completions and the 4 inductions. The remainder of the table is for SRUs. We can see, for example, that 9 type-8 SRUs were to be repaired, 5 to fix AWP LRUs and 2 each for inducting LRUs and to be sent to bases.

Allocations

The *d* option (for "distribution") brings up the display in Figure 5.6 showing how many of each item has been allocated to each base. The total of 14 LRUs is more than the 11 shown on the first line of the data. Were the display to be scrolled across bases with the arrow keys, the other 3 would be found.

Current Stock

Pressing the *s* key gives the matrix of asset positions illustrated by Figure 5.7. The entries are stock minus holes. Since DRIVE maintains the condition that both cannot be positive, the assumption is that a positive number indicates serviceable stock at a base, and a negative number implies the existence of AWP LRUs. This is not true for the depot because the depot does not always cannibalize, but numbers shown in the depot column are still computed in the same way. Note that there are still SRU holes shown for Moody and Homestead (bases 1 and 2). Moreover, a package of SRUs for Homestead would consist of SRUs 4 and 8.

Graphical Display of Asset Positions

Although complex, the graphs as illustrated by Figure 5.8 have been found to be revealing. (They are easier to digest on a color screen.) Bases are indicated across the top as on the main screen. Rows labeled "Pr 1" and "Pr 2" are probabilities that the bases will meet their goals with respect to this LRU family. The Pr 1 row has the initial probabilities and does not change; the Pr 2 row contains probabilities corresponding to the allocations so far and agrees with the "PrOK" row on the main screen. The vertical axis is counts of LRUs. For each base, there are two stacks of bars. The left stack, consisting of a wide bar on the bottom crowned with a slender bar, is about demands. The right-hand stack of bars relates to LRUs.

```
            LRU NSN 1270-01-209-9982WF  COMPUTER   GAME.DAT [12]
      1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
     MOO HOM TIN MCE HIL GRE HAN FOR CAP ATL KEL WRI FAR AND SEL FRE MCC  -->
     .41 .36 .48 .50 .64 .51 .49 .64 .47 .51 .54 .69 .49 .89 .69 .75 .76

Item                              ALLOCATIONS                              Total
 0 |  .   .   .   .   .   3   2   .   1   3   .   .   .   .   .   1   1 |   14
 1 |  .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   . |    0
 2 |  .   .   .   .   .   .   .   .   2   .   .   .   .   .   .   .   . |    2
 3 |  .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   . |    0
 4 |  .   .   .   .   .   .   .   .   1   .   .   .   .   .   .   .   . |    1
 5 |  .   .   .   .   .   .   .   .   2   .   .   .   .   .   .   .   . |    2
 6 |  .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   . |    1
 7 |  .   .   .   1   .   .   .   .   .   .   .   .   .   .   .   .   . |    2
 8 |  .   .   .   .   1   .   .   .   .   .   .   .   .   .   .   .   . |    2
 9 |  .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   . |    0
10 |  .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .   1 |    4
11 |  .   .   .   .   .   .   .   .   .   .   .   1   .   .   .   .   1 |    2

Press Enter to return to main screen:
```

Figure 5.6—Display Allocations

```
                 LRU NSN 1270-01-209-9982WF  COMPUTER   GAME.DAT [12]
        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
      MOO HOM TIN MCE HIL GRE HAN FOR CAP ATL KEL WRI FAR AND SEL FRE MCC  -->
PrOK  .41 .36 .48 .50 .64 .51 .49 .64 .47 .51 .54 .69 .49 .89 .69 .75 .76
Dmnd   16  14 5.2 4.9 4.8 4.0 4.0 4.0 3.9 3.9 3.8 3.4 3.1 1.6 1.2 1.0 1.1
AWPs    1   1   .   .   .   .   .   .   .   .   .   .   .   .   .   .   .
Item                              CURRENT STOCK                           Depot
 0 |    2   1   .   1   2   3   3   1   3   3   .   1   .   .   .   1   1    .
 1 |    1   .   .   1   5   2   .   .   .   .   .   .   .   .   .   .   .    2
 2 |    .   1   1   .   1   1   .   .   .   .   .   .   .   .   .   .   .    .
 3 |    .   5   .   4   .   .   .   .   .   .   .   .   .   .   .   .   .    7
 4 |    .  -1   4   .   1   .   .   .   .   .   4   .   .   .   .   .   .    .
 5 |    4   8   .  11   8   8   8   .   .   .   .   .   .   .   .   .   4    .
 6 |    .   8   .   .   4   .   4   4   .   4   .   8   .   4   .   4   .    .
 7 |    .   .   .   .   4   .   .   .   .   .   4   .   .   .   .   .   .    1
 8 |   -1  -1   .   .   .   .   .   4   .   .   .   .   .   .   .   .   .    .
 9 |    1   2   .   1   3   .   .   .   .   .   .   .   .   .   .   .   1    .
10 |    .   .   1   .   1   1   .   .   .   .   3   .   .   .   .   1   1    .
11 |    .   1   2   .   .   1   .   1   1   .   .   .   .   .   .   .   1    .



Press Enter to return to main screen:
```

Figure 5.7—Display Stock at Bases

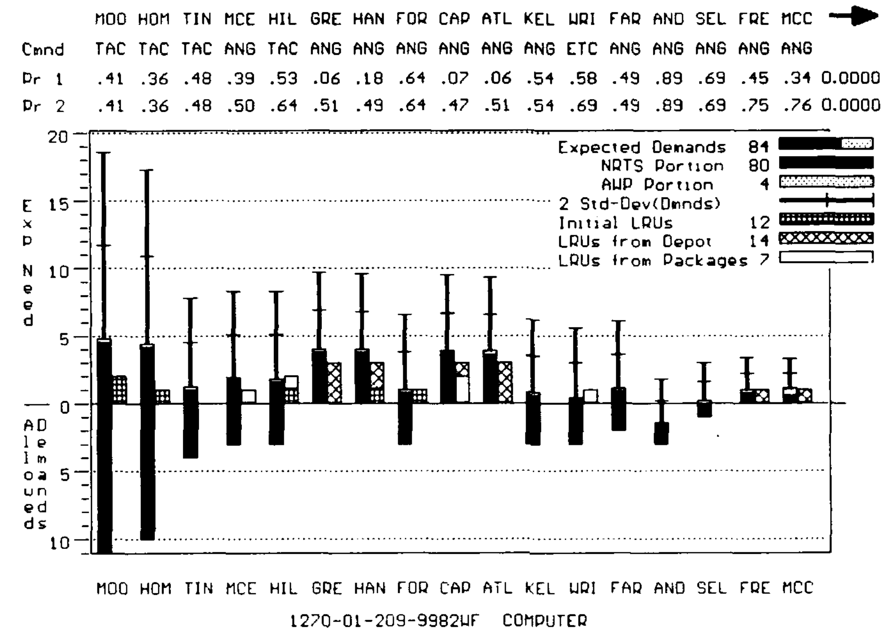

Fig. 5.8—Bar Graph of Base Asset Positions

The wide part of the demand-bar stack is expected demand. As indicated by the legend, this is in two parts. The solid portion is the expected number of LRUs returned to the depot during the base's horizon. On top of that is a portion filled with dots indicating the number of LRUs expected to enter the base's repair shop, although with these data, the numbers are too small to be visible. Moody's bar is a little less than 16 LRUs high. Note that there is a zero on the vertical scale, and Moody's demand bar extends from –11 to nearly +5. This is because Moody is a WRSK base and is allowed to have 11 LRUs missing from aircraft at the end of its horizon plus 30 days of wartime operation. Moving its demand bar downward by that amount provides a more meaningful representation of the comparison between LRUs at the base and demand, since DRIVE's priority calculation is based on the probability that demand minus allowable LRUs missing is less than stock.

The spike on top of the expected-demand bar indicates two standard deviations in order to emphasize that having enough LRUs to meet just *expected* demands may not be a very strong asset position.

The LRU bars are of three kinds. On the bottom of the stack, with horizontal and vertical hatching, is the number of LRUs that the base

had before any allocations. If the base has had any of its own AWP LRUs taken care of with packages of SRUs, the number is shown by an empty bar. The fifth base, Hill, started with one LRU in stock and obtained another because of a package of SRUs. LRUs sent from the depot are represented by bars with diagonal hatching. The seventh base, Hancock, started with one LRU and has been allocated two more.

Figures 5.9 and 5.10 are the main screen and graph that resulted from choosing the *a* option; they represent the status with respect to this LRU if all the repairs and allocations computed by the LSRU program prior to stopping with a sort value of 0.0005 were to be carried out.

```
                LRU NSN 1270-01-209-9982WF   COMPUTER    GAME.DAT [12]
        1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17
      MOO HOM TIN MCE HIL GRE HAN FOR CAP ATL KEL WRI FAR AND SEL FRE MCC  -->
PrOK .47 .44 .50 .52 .65 .66 .65 .65 .66 .68 .68 .71 .65 .89 .69 .75 .85

WRM     0  14   3   0  13   1   2   3   0   1   0   0   0   2   0   0   0
Dmnd   16  14 5.2 4.9 4.8 4.0 4.0 4.0 3.9 3.9 3.8 3.4 3.1 1.6 1.2 1.0 1.1
Stck    3   2   0   1   2   4   4   1   4   4   1   1   1   0   0   1   1
-----------------------------------------------------------------------------
SRU     0   1   2   3   4   5   6   7   8   9  10  11
QPA     1   1   1   1   1   1   1   1   1   1   1   1

          LUKE ARIZONA          0 AWP LRUs
Stck    1   0   2   1   1   1   1   2   1   1   1   1
Hole    0   0   0   0   0   0   0   0   0   0   0   0

          DEPOT                 0 AWP LRUs
Stock   0   1   0   0   0   0   0   0   0   0   0   0
MIC S       0   0   0   0   0   0   0   0   0   0   0
Holes       0   0   0   0   0   0   0   0   0   0   0
Reps    0  29  49   9  13  10  24 122  22   0   0  26

-----------------------------------------------------------------------------
No more allocations.      Update status:      |Xactn Steps Hours   Prob SortVal
All displays are available (q to quit):       |  977   143  1603 0.0003 0.00049
```

Figure 5.9—Main Screen After 143 Allocation Steps

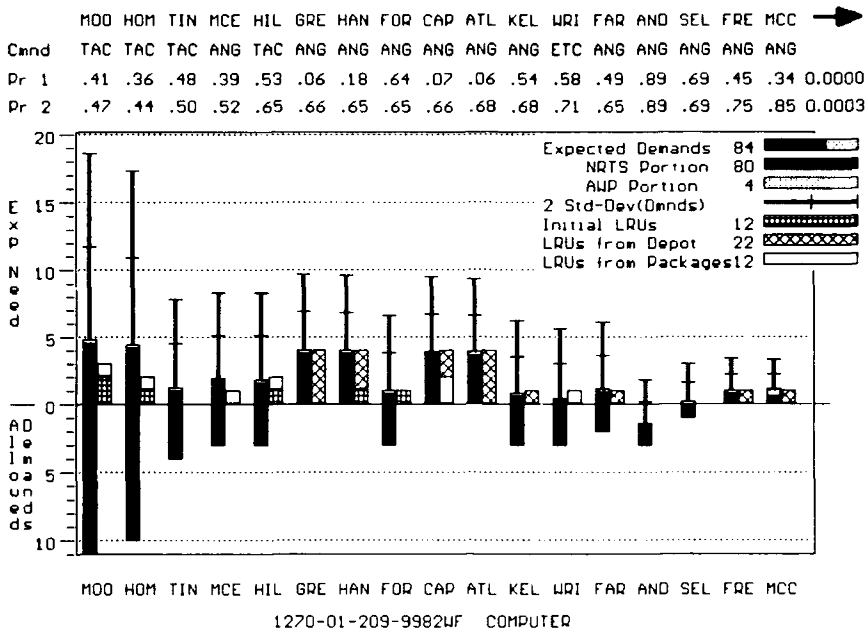

Figure 5.10—Bar Graph of Base Status After 143 Allocation Steps

6. QUARTERLY PLANNING WITH DRIVE

Although DRIVE is intended to replace the prevailing discipline of working toward goals negotiated under the MISTR (Management of Items Subject to Repair) system, the ALC is still in need of a mechanism to estimate repair quantities by quarters for manpower planning, ordering parts, and the like. In particular, the total number of shop hours to be devoted to the repair of the "DRIVE items" is still a subject for negotiation. Since DRIVE produces plans covering only a small portion of a quarter and is intended to be responsive to unpredicted events, it is not reasonable to expect highly accurate forecasts of the aggregate of several DRIVE production lists. This raises the question, Can useful estimates of quarterly repair quantities be made?

It is difficult to develop a method that is both theoretically satisfactory and computationally feasible because of the fundamental way in which DRIVE views the world. DRIVE is based on the assumption that a set of decisions is made and acted upon at one point in time and the effects are felt at a later time point. On the other hand, the quarterly planning problem is to predict the total number of items to be repaired over a sequence of horizons, rather than just one. There have been a number of proposals for utilizing DRIVE's single-period computation to predict the aggregate results from a sequence of DRIVE production plans over a longer time. This section describes the proposal that appears to be the best and includes results from a simulation constructed for studying quarterly planning methods.

A METHOD FOR ESTIMATING QUARTERLY REPAIR QUANTITIES

Out of the half dozen approaches to quarterly planning that have been considered, the best one so far was suggested by Salvatore Culosi of LMI.[1] Culosi's idea seems quite simple: pretend that the entire quarter's repairs will be done in the last production period of the quarter.

[1]Culosi, Salvatore J., *An Analysis of Issues Related to Implementing the DRIVE Model*, Logistics Management Institute, Report AF002R1, April 1991.

The calculation is like the normal biweekly DRIVE computation, except for two things. First, the standard repair hours available in the various shops are set equal to the quarterly totals. Second, the expected numbers of NRTS items from the bases are computed based on peacetime flying rates over a time interval equal to one-quarter less one production period. (If a quarter is 90 days, and a production period covers 14 days, the interval would be 76 days.) The bases' asset positions are reduced and the numbers of repairable carcasses at the depot are increased by the expected NRTS quantities. The adjustment for expected NRTS serves both to reflect losses of items at the bases and provides an estimate of additional carcasses available at the depot. There are two appealing features about Culosi's method. First, it uses the same probability functions as does the biweekly DRIVE, implying that both the quarterly and biweekly uses of DRIVE are working to achieve the same objective function. Second, the accounting for NRTS items and carcasses is correct in the sense of expected values.

OTHER METHODS

Other methods that have been investigated were of two varieties. One group involved lengthening the planning horizon to 90 days. The fallacy in lengthening the horizon is that the biweekly and quarterly models would be using different probability functions for evaluating the objective function. The second group of methods was motivated by the distinction between catch-up and keep-up requirements discussed in Section 2 of the companion report.[2] These methods are schemes to use DRIVE to arrive at a "desired asset position" (the catch-up requirement) and then add more repairs to maintain that asset position by fixing the expected numbers of items that would fail.

SIMULATION OF QUARTERLY PLANNING

Richard Moore at Headquarters AFLC carried out a deterministic simulation of several quarterly planning methods. To estimate the effect of DRIVE's biweekly plans over a quarter, he started with the asset position from a DRIVE database and made six biweekly plans. Between plans, asset positions at bases were decreased by the expected NRTS quantities, and numbers of carcasses available at the depot were increased by the same amounts. It was assumed that

---

[2]Abell, John B., et al., *DRIVE (Distribution and Repair in Variable Environments)* R-3888-AF, 1992.

each biweekly plan was carried out exactly and the bases' asset positions were augmented by the planned allocations from the depot. For simplicity, the exercise dealt only with LRUs. Moore's result was that the quarterly plan made by the Culosi method agreed almost exactly with the sum of repairs called for in the six biweekly plans. None of the other methods tested showed the same level of agreement.

Subsequent to Moore's demonstration, we wrote a simulation program to perform similar analyses, except that the NRTS actions are sampled using the Monte Carlo method. Introducing random variables in place of expected values is important for making comparisons because results from a deterministic simulation are misleading in that they suggest that quarterly planning can produce error-free predictions. The Monte Carlo model also only deals with LRUs since the inclusion of SRUs in DRIVE accounts for most of its complexity and computer time. As in Moore's deterministic analysis, the simulation assumes that biweekly plans are carried out exactly.

Some of the options available in our simulation and the specific choices made to produce the results presented here are outlined below.

Treatments

- Four methods of quarterly planning are available, although we only include results for Culosi's method here.
- Reallocation of base assets prior to making biweekly and quarterly plans is a selectable option. Reallocation was not exercised in the case discussed here.

LRUs in the Test

- We included 14 LRUs repaired on the CI test stand with data taken from the PPOUT.DAT of 9 May 1990.

NRTS Parameters

- NRTS LRUs within each biweekly period are sampled from a negative binomial distribution.
- Expected NRTS used in the DRIVE computations were also used as the mean values in the Monte Carlo sampling of NRTS.

- Biweekly and quarterly planning methods employed the Sherbrooke regression applied to base mean (i.e., not worldwide) for VTMRs.
- For sampling NRTS, the VTMR was set to 4.0 for all LRUs at all bases. This was done to have more variability than DRIVE was expecting.

Trials and Sample Size

- A trial consists of five quarters, and each trial began with the asset position as specified in the PPOUT.DAT file. Data from the first quarter of each trial was ignored.
- Eight trials were made, giving a sample size of 32 quarters and 192 biweekly periods.

Event Timing Within a Trial

- Biweekly plans were done every 14 simulated days.
- A quarterly plan was done every 84 days beginning with the second simulated quarter in a trial. A quarter covers six biweekly periods.
- For biweekly plans, the NRTS were sampled and the asset position was recorded on the day before the plan was computed. Asset positions of the bases were updated on the day after the plan was made.
- Asset positions for making quarterly plans were recorded two days after the third biweekly plan in the previous quarter so that the LRUs to be repaired according to that plan would have been delivered to bases. This is the reason data from the first quarter in a trial are discarded.

Repair Capacity

- The total quarterly keep-up requirement represents 3458 standard hours (see Table 6.1).

- Biweekly and quarterly plans were made to include 634 and 3804 standard hours, respectively. These values are 110 percent of the keep-up requirement.

Table 6.1

Sampling Quarterly NRTS and Keep-Up Requirement

LRU	Expected NRTS	Sample Avg NRTS	Sample VTMR	Sample Std-Dev	Repair Hours	E(NRTS) × Hours
3976 FIRE COMP	6.24	5.34	3.61	4.39	9.2	57.38
3829 XFCC	3.44	3.44	2.72	3.06	4.0	13.76
3533 FC NAV PAN	72.31	72.38	3.42	15.72	8.5	614.60
6645 INU	37.36	35.69	3.08	10.48	29.0	1083.32
7817 ACCELER AS	6.73	6.81	2.51	4.13	8.0	53.83
0046 ECA	12.09	11.44	3.87	6.65	11.0	132.99
0712 ECA C/D	23.10	23.34	3.51	9.05	11.0	254.07
7834 GYRO	16.54	15.06	3.91	7.68	6.5	107.48
3160 PANEL	26.43	25.84	2.69	8.33	8.0	211.46
7445 PANEL TRIM	66.95	68.75	3.19	14.82	6.6	441.88
1592 FLT CTL CO	7.41	6.97	4.14	5.37	22.6	167.40
0136 FLCC	4.05	2.22	3.22	2.67	22.6	91.53
3851 FL CTL CTR	13.21	13.34	5.46	8.54	12.0	158.51
6771 RECORD ASY	8.34	8.09	2.77	4.74	8.4	70.03
Total hours	3458.25	3344.29				3458.25

NOTE: The numbers above are rounded and do not add up exactly to the totals.

RESULTS

Table 6.1 contains information related to sampling NRTS. For each of the 14 LRUs, it shows the mean of the quarterly NRTS along with the average observed VTMR (to compare with the specified VTMR of 4.0) and standard deviation obtained for the 32 quarters in the samples. Also indicated are the LRUs' standard repair hours and the product of the mean NRTS and standard hours. This product represents the keep-up requirements in hours. Note that 3533 FC NAV PAN and 6645 INU together account for nearly half of the keep-up requirement.

Table 6.2 compares biweekly plans with the quarterly plans made by the Culosi method without reallocation. The rightmost panel shows observed average[3] and standard deviations of differences between the totals of biweekly plans and their corresponding quarterly plans. The largest difference is less than four LRUs in absolute value, which indicates that, on average, the differences are small. On the other

[3]The sum of six biweekly plans calls for more repair hours than the associated quarterly plan because the marginal allocations are terminated with the first repair for which the total hours exceed the limit. This happens six times in a quarter for biweekly plans, but only once for the quarterly computation.

Table 6.2

Comparison of Biweekly and Quarterly Plans

LRU	Biweekly Plans		Quarterly Plans		Difference (B–Q)	
	Average	Std-Dev	Average	Std-Dev	Average	Std-Dev
3976 FIRE COMP	6.97	3.92	6.19	3.04	0.78	4.14
3829 XFCC	3.16	3.00	3.00	0.00	0.16	3.00
3533 FC NAV PAN	84.69	21.09	82.25	14.06	2.44	16.58
6645 INU 74DA0	42.41	9.32	44.13	11.20	–1.72	10.31
7817 ACCELER AS	7.25	3.78	5.94	2.58	1.31	3.44
0046 ECA 14FB0	11.63	5.07	10.09	8.73	1.53	5.02
0712 ECA C/D	20.50	8.55	17.17	10.39	3.31	8.60
7834 GYRO	16.66	8.28	17.16	5.98	–0.50	6.99
3160 PANEL	32.25	8.13	30.22	6.09	2.03	7.76
7445 PANEL TRIM	80.69	15.39	84.44	6.10	–3.75	15.41
1592 FLT CTL CO	7.72	4.64	6.22	2.76	1.50	4.33
0136 FLCC	6.56	3.72	9.78	4.38	–3.22	3.84
3851 FL CTL CTR	10.00	6.64	7.97	4.31	2.03	6.44
6771 RECORD ASY	9.34	4.04	5.84	3.49	3.50	4.49
Total hours	3857.78		3812.47		45.65	

NOTE: The numbers above are rounded and do not add up exactly to the totals.

hand, what is important is how good a predictor a quarterly plan is oi the biweekly plans to be executed during the quarter. Some feeling for this can be obtained by examining the standard deviations of the differences in the rightmost column. While one would like to see smaller numbers, they are very similar to the standard deviations of the sampled quarterly NRTS in Table 6.1. The standard deviations in Table 6.1 represent the inherent variability of the NRTS process, and one should not expect a method for quarterly planning to do better.

Table 6.3 shows the fractions of plans for which carcass constraints were binding. This is important to observe because if carcass constraints are frequently active, there are not many degrees of freedom in planning; a plan would simply call for repairing all the carcasses that are available.

To give an overall score for an experiment, the simulation reports a root-mean-square (RMS) measure of the differences between quarterly and biweekly quantities. For the conditions of the experiment, there were observed differences on 14 LRUs over 32 quarters. This gave 448 observations. To calculate the RMS measure, we summed the squares of the 448 numbers, divided by 448, and took the square

Table 6.3

Percent of Plans Limited by Carcass Constraints

LRU	Biweekly	Quarterly
3976 FIRE COMP	0.0	0.0
3829 XFCC	0.0	100.0
3533 FC NAV PAN	2.9	46.9
6645 INU	4.8	81.3
7817 ACCELER AS	0.0	0.0
0046 ECA	0.0	0.0
0712 ECA C/D	0.0	0.0
7834 GYRO	0.0	0.0
3160 PANEL	0.0	0.0
7445 PANEL TRIM	0.0	0.0
1592 FLT CTL CO	0.0	0.0
0136 FLCC	0.0	0.0
3851 FL CTL CTR	0.0	0.0
6771 RECORD ASY	0.0	0.0
Number plans in sample	192	32

root. The answer in this case was 8.4. Among the other three planning methods that were tested, the best gave a result of 13.5.

There is reason to believe that the RMS value of 8.4 is about as good as one can expect given the variability in the simulated NRTS process. To obtain a value for comparison, assume a simpler process than DRIVE for which the appropriate quarterly planning method is obvious. Instead of using DRIVE, suppose the shop simply repairs everything that is sent to it in each quarter. Then each of the 448 observations of quarterly repairs would be equal to the sampled NRTS quantities, and the best predictions of quarterly repairs would be the mean values in the first column of Table 6.1. Computing RMS values from these data gave a value of 8.3, which is not much less than 8.4.

Appendix A

DRIVE'S SENSITIVITY TO VTMRS

As described in Section 3, DRIVE utilizes the Sherbrooke regression to determine variance-to-mean ratios as functions of the mean for probability distributions of unserviceable items returned to the depot by the bases. Although many stockage and capability assessment models used by the Air Force incorporate estimates of VTMRs, there is much about VTMRs that is unsettling. Hodges[1] has discussed the undesirable sampling properties of the statistic used to estimate VTMRs. Crawford,[2] working with empirical data on demands for aircraft spare parts, documents rather wild behavior of demand processes. Of particular interest are Figures 1 and 2 in Crawford's report displaying scatter diagrams of VTMRs versus average demands per quarter. The vertical dispersion of VTMRs appears so great that one must seriously question the idea of fitting a regression curve to the data. But our concern is not the accuracy of estimates of VTMRs per se, but what difference VTMR estimates make to DRIVE.

To gain some insight about the sensitivity of DRIVE to VTMRs, we modified the prioritization program (LSRU) to employ a variety of ways of setting VTMRs and then used the line-drawing program described in Section 4 to produce counts of LRUs to be repaired under a consistent set of capacity constraints over the various trials.

In addition to DRIVE's "standard" VTMR computation, the LSRU program was modified to accept a user-specified, constant VTMR to be employed for all items at all bases. This variant was tried with VTMRs equal to 1, 2, 4, and 8.[3] A second modification was to the way in which the Sherbrooke regression was applied. Although the formula, which says that the VTMR is proportional to the square root of the annual mean demand, was derived from worldwide data, we were using it with each base's individual mean. Therefore, we modified the LSRU program to employ the sum of base means for each item and then used the resulting VTMR for the item at every base. This obvi-

[1]Hodges, James S., *Modeling the Demand for Spare Parts: Estimating the Variance-to-Mean Ratio and Other Issues,* RAND, N-2086-AF, May 1985.

[2]Crawford, Gordon B., *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications,* RAND, R-3318-AF, January 1988.

[3]Crawford's data on 800 F-15 parts, with VTMRs measured around worldwide averages, showed less than 15 percent of parts having VTMRs greater than 8.

ously results in much higher VTMRs. Table A.1 compares the demands and VTMRs for 41 LRUs corresponding to the two methods: treating bases individually versus worldwide totals. For the individual-base case, demands and VTMRs are averaged over bases that have positive demand for the LRU. (It is not possible to compute the VTMR columns from the data in the demand columns because all the entries are averages over bases.) In all, there were six trials: the Sherbrooke regression applied to individual bases and to the sum of base means, plus the four values of constant VTMRs.

In each case, the line-drawing program was used to specify a total of 3000 standard repair hours across the four LRU test stands, with no stand allowed to have more than 1500 hours. In all cases, the 1500-hour constraint was active for the CI stand, and the other test stands share the remaining 1500 hours in amounts varying with the case.

Table A.2 shows the numbers of LRUs to be repaired for six cases, along with the LRUs' standard repair hours and number of repairable carcasses available. Although carcass constraints were imposed, the effect is confined mainly to the inertial navigation unit (INU), line 3. That LRU has the highest demand and 32 INU repairs, which occurred in five of the six cases, and consumes 928 of the 1500 hours on the CI stand.

We do not have an objective measure of the sensitivity revealed by this test, but the sensitivity is not large enough to worry about.[4]

Because this is real data and the situation is complicated (e.g., what is the role of bases' asset positions?), it is difficult to make generalizations about the effects of varying VTMRs. As VTMRs increase, the LRUs that increase the most have low values of repair hours (see lines 10, 15, and 27). The exception to this is line 3; the fire control/navigation panel (FC NAV PAN) has one of the smallest repair hour requirements, but the number of repairs called for decreases with VTMR. We note that this LRU has a very high demand rate, but then so does the missile release interface unit (MRIU) on line 27. Looking at the distributions of the 1500 hours left for the DI, PP, and RF test stands, as the VTMRs increase, the DI and PP stands take more hours at the expense of the RF stand. A possible cause is that the LRUs repaired on the RF stand all have standard hours greater than the average, which is 17.7.

[4]Crawford's report shows a graph (Figure 3) of expected not fully mission-capable (NFMC) aircraft by day in a scenario as given by a capability assessment model assuming several values of VTMRs. In that exercise, the sensitivity seems to be rather strong.

Table A.1

Demands and VTMRs

Line	NSN	Description	Individual Bases: Number Bases	Individual Bases: Avg Demand	Individual Bases: Avg VTMR	Worldwide: Total Demand	Worldwide: VTMR
	CI Stand						
1	1270-01-045-3976WF	FIRE COMP	29	1.326	1.474	38.442	4.215
2	1270-01-222-3829WF	XFCC	29	0.731	1.352	21.193	3.387
3	6605-01-046-3533WF	FC NAV PAN	29	5.412	2.038	156.944	7.501
4	6605-01-087-6645WF	INU	29	8.608	2.201	249.624	9.193
5	6610-01-039-7817WF	ACCELER AS	38	0.478	1.299	18.163	3.180
6	6610-01-123-0046WF	ECA	29	2.568	1.660	74.484	5.476
7	6610-01-148-0712WF	ECA D/C	16	3.959	1.820	63.351	5.020
8	6615-01-042-7834WF	GYRO	38	1.611	1.535	61.233	5.008
9	6615-01-127-3160WF	PANEL	38	1.937	1.600	73.620	5.390
10	6615-01-129-7445WF	PANEL TRIM	38	1.930	1.639	73.353	5.350
11	6615-01-161-1592WF	FLT CTL CO	29	1.210	1.461	35.095	4.073
12	6615-01-172-0136WF	FLCC	29	1.262	1.451	36.590	4.137
13	6615-01-220-3851WF	FL CTL CTR	16	3.207	1.712	51.320	4.626
14	6625-01-114-6771WF	RECORD ASY	38	0.240	1.226	9.129	2.535
	DI Stand						
15	1270-01-094-6872WF	RCP	29	1.254	1.523	36.357	4.132
16	1270-01-122-9955WF	HUD ELECT	29	1.275	1.445	32.697	3.966
17	1270-01-199-7430WF	HUD PDU	29	3.070	1.738	89.040	5.894
18	1270-01-274-0543WF	HUD EU ADE	29	0.483	1.292	14.015	2.942
19	5841-01-096-3945WF	DISP	29	2.559	1.696	74.204	5.469
20	5841-01-096-4833WF	RDR	29	2.279	1.653	66.096	5.218
	PP Stand						
21	1270-01-133-6494WF	DIG SIG PR	29	2.703	1.702	78.395	5.593
22	1270-01-209-9982WF	RADC	29	2.884	1.732	83.632	5.744
23	1270-01-212-2990WF	DISP ADF	29	0.557	1.323	16.141	3.084
24	1270-01-273-3858WF	OCU RADC	26	0.256	1.203	7.429	2.413
25	1270-01-273-3859WF	S2 RADC	29	1.576	1.538	45.694	4.507
26	1270-01-282-7914WF	ADF RADC	15	0.186	1.211	2.796	1.867
27	1280-01-109-1499WF	MRIU	38	4.252	1.905	161.587	7.541
28	1280-01-121-6879WF	SCP	29	1.205	1.510	34.934	4.069
29	1280-01-224-8924WF	XCIU	29	1.488	1.496	43.145	4.406
30	1280-01-280-4855WF	CIU-S2	29	2.402	1.650	69.656	5.329
31	1290-01-080-0203WF	CRIU	29	1.623	1.556	47.073	4.560
32	5999-01-080-3978WF	JRIU	38	1.487	1.530	56.502	4.844
33	6610-01-089-1018WF	COMPUTR CA	38	3.074	1.752	116.799	6.531
34	6615-01-042-7835WF	PNE SENSOR	38	0.533	1.326	20.253	3.297
	RF Stand						
35	1270-01-093-2174WF	ANTENNA RA	29	3.272	1.836	94.888	6.058
36	1270-01-093-2256WF	RADAR XMTR	29	3.192	1.758	92.572	5.991
37	1270-01-102-2962WF	LOW PWR RF	29	2.002	1.582	58.065	4.952
38	1270-01-102-2963WF	LOW PWR RF	29	2.001	1.582	58.035	4.951
39	1270-01-102-2965WF	LOW PWR RF	29	2.914	1.824	76.416	5.534
40	1270-01-102-2966WF	LOW PWR RF	28	2.635	1.684	79.560	5.626
41	1270-01-146-4630WF	ANTENNA	29	0.872	1.430	25.297	3.611

Table A.2

Sensitivity of Biweekly Production Plans to Variance-to-Mean Ratios

Line	NSN	Description	Variance-to-Mean Ratio: Sherbrooke Total	Sherbrooke Bases	Constant 1.0	Constant 2.0	Constant 4.0	Constant 8.0	Std. Hours	Repar-ables
	CI Stand									
1	1270-01-045-3976WF	FIRE COMP	1	1	1	1	1	1	9.2	27
2	1270-01-222-3829WF	XFCC	—	—	—	—	—	—	4.0	—
3	6605-01-046-3533WF	FC NAV PAN	31	22	38	34	31	28	8.5	128
4	6605-01-087-6645WF	INU	32	31	32	32	32	32	29.0	32
5	6610-01-039-7817WF	ACCELER AS	2	2	2	2	2	1	8.0	51
6	6610-01-123-0046WF	ECA	—	—	—	—	—	—	11.0	40
7	6610-01-148-0712WF	ECA D/C	—	—	—	—	—	—	11.0	16
8	6615-01-042-7834WF	GYRO	3	5	2	2	2	3	6.5	41
9	6615-01-127-3160WF	PANEL	2	4	—	2	1	2	8.0	99
10	6615-01-129-7445WF	PANEL TRIM	28	38	23	29	34	38	6.6	220
11	6615-01-161-1592WF	FLT CTL CO	1	—	1	—	—	—	22.6	46
12	6615-01-172-0136WF	FLCC	1	1	1	1	1	1	22.6	40
13	6615-01-220-3851WF	FL CTL CTR	1	1	1	1	1	1	12.0	10
14	6625-01-114-6771WF	RECORD ASY	1	5	1	1	1	—	8.4	58
		Hours	1503	1503	1507	1506	1505	1504		
	DI Stand									
15	1270-01-094-6872WF	RCP	17	26	6	17	25	31	6.3	73
16	1270-01-122-9955WF	HUD ELECT	4	5	2	2	3	2	19.5	19
17	1270-01-199-7430WF	HUD PDU	8	7	6	7	9	9	20.3	10
18	1270-01-274-0543WF	HUD EU ADE	—	—	—	—	—	—	19.5	15
19	5841-01-096-3945WF	DISP	1	2	1	1	3	3	12.2	104
20	5841-01-096-4833WF	RDR	4	4	8	4	4	4	26.1	37
		Hours	464	532	263	405	540	558		
	PP Stand									
21	1270-01-133-6494WF	DIG SIG PR	—	—	—	—	—	—	11.4	4
22	1270-01-209-9982WF	RADC	2	2	2	2	2	2	26.0	2
23	1270-01-212-2990WF	DISP ADF	—	—	—	—	—	—	11.4	—
24	1270-01-273-3858WF	OCU RADC	—	—	—	—	—	—	26.0	—
25	1270-01-273-3859WF	S2 RADC	—	—	1	—	—	—	26.0	6
26	1270-01-282-7914WF	ADF RADC	1	1	1	1	1	1	5.0	1
27	1280-01-109-1499WF	MRIU	18	22	16	19	28	39	7.3	327
28	1280-01-121-6879WF	SCP	10	11	6	10	10	10	20.7	44
29	1280-01-224-8924WF	XCIU	—	—	—	—	—	—	23.8	12
30	1280-01-280-4855WF	CIU-S2	3	4	3	5	6	5	15.8	12
31	1290-01-080-0203WF	CRIU	1	2	1	1	1	2	12.1	94
32	5999-01-080-3978WF	JRIU	2	3	—	2	3	3	12.1	19
33	6610-01-089-1018WF	COMPUTR CA	1	1	1	—	1	2	10.6	66
34	6615-01-042-7835WF	PNE SENSOR	5	5	4	5	5	5	16.2	5
		Hours	571	661	423	599	703	790		
	RF Stand									
35	1270-01-093-2174WF	ANTENNA RA	—	—	4	—	—	—	42.0	98
36	1270-01-093-2256WF	RADAR XMTR	—	—	—	—	—	—	24.4	15
37	1270-01-102-2962WF	LOW PWR RF	—	—	—	—	—	—	33.2	4
38	1270-01-102-2963WF	LOW PWR RF	2	4	6	3	1	1	26.7	11
39	1270-01-102-2965WF	LOW PWR RF	2	—	3	1	—	—	26.7	13
40	1270-01-102-2966WF	LOW PWR RF	12	6	14	13	7	3	26.7	14
41	1270-01-146-4630WF	ANTENNA	1	1	1	1	1	1	42.0	29
		Hours	469	309	824	496	256	149		

NOTE: The numbers above represent the number of LRUs repaired.

Appendix B
SENSITIVITY OF DRIVE TO PLANNING HORIZONS

The concept of planning horizons is central to DRIVE. A planning horizon is the nominal time between when the asset position data used by DRIVE were recorded and when decisions made by DRIVE will have an effect on the bases to which LRUs and SRUs are allocated. The specific role that the lengths of planning horizons play in DRIVE is as multipliers of demand rates for items from bases in the computation of expected demands. These expected demands, in turn, are the basis of the probability distributions that make up DRIVE's objective function and are used in the marginal analysis. The purpose of this appendix is to provide some notion as to the sensitivity of DRIVE to the lengths of planning horizons. Although planning horizons are important to the underlying theory, one would hope that the priority lists are not overly sensitive to the actual values used.

To test the sensitivity, we ran DRIVE with three values for planning horizons equal to 26, 39, and 52 days—the lowest number being the average horizon as DRIVE is used at Ogden and the highest number being twice that. (These values are approximate because DRIVE adjusts each base's individual planning horizon according to its specific nominal shipping times.) To produce the priority lists, we employed the line-drawing program, specifying standard hours for the four AIS test stands close to the values that were being used at Ogden at the time this analysis was done. The hours were: 600 on the CI stand, 450 on the DI stand, and 500 each on the PP and RF stands. Table B.1 shows the number of each LRU to be repaired for each of three lengths of planning horizon. Except for the 1499 MRIU (fifth LRU on the PP stand), the values seem to be quite stable across the three horizon lengths.

Table B.1

Sensitivity of Biweekly Production Plans to Length of the Planning Horizon

NSN	Description	Approximate Horizon 26 days	39 days	52 days
CI Stand				
1270-01-045-3976WF	FIRE COMP	2	1	1
1270-01-222-3829WF	XFCC	3	4	2
6605-01-046-3533WF	FC NAV PAN	12	11	15
6605-01-087-6645WF	INU	6	6	6
6610-01-039-7817WF	ACCELER AS	2	3	2
6610-01-123-0046WF	ECA	2	2	1
6615-01-042-7834WF	GYRO	7	7	4
6615-01-127-3160WF	PANEL	8	7	8
6615-01-129-7445WF	PANEL TRIM	8	11	15
6615-01-161-1592WF	FLT CTL CO	1	0	1
6615-01-172-0136WF	FLCC	1	1	0
6615-01-220-3851WF	FLCC	1	2	1
6615-01-324-6374WF	FLCC	1	1	1
6625-01-114-6771WF	RECORD ASY	1	1	1
DI Stand				
1270-01-094-6872WF	RCP	1	1	0
1270-01-122-9955WF	HUD ELECT	3	2	0
1270-01-199-7430WF	HUD PDU	5	4	4
1270-01-274-0543WF	HUD ELEC U	1	0	0
5841-01-096-3945WF	REO DISP	14	15	15
5841-01-096-4833WF	REO EU	4	6	8
PP Stand				
1270-01-133-6494WF	DIG SIG PR	3	3	1
1270-01-273-3858WF	RADC OCU	1	1	1
1270-01-273-3859WF	RADC S2	1	1	1
1270-01-282-7914WF	RADC ADF	2	1	1
1280-01-109-1499WF	MRIU	11	21	28
1280-01-121-6879WF	SCP	5	4	2
1280-01-280-4855WF	CIU-S2	3	3	3
1290-01-080-0203WF	CRIU	2	1	1
5999-01-080-3978WF	JRIU	1	0	4
6610-01-089-1018WF	CADC 507	1	1	1
6610-01-308-1859WF	CADC 509	1	1	1
6615-01-042-7835WF	PNE SENSOR	5	5	3
RF Stand				
1270-01-093-2256WF	RADAR XMTR	2	3	4
1270-01-102-2962WF	LOW PWR RF	7	7	7
1270-01-102-2963WF	LOW PWR RF	0	1	2
1270-01-102-2965WF	LOW PWR RF	8	8	7
1270-01-102-2966WF	LOW PWR RF	2	0	0

NOTE: The numbers above represent the number of LRUs repaired.

Appendix C

INPUT AND OUTPUT FILES FOR THE LSRU PROGRAM

The computer program described in Section 3 is called LSRU, a contraction of LRU and SRU. It reads two input files—LSRUMGT.DAT and LSRUDET.DAT—and it writes four output files—ITEMMGR.DAT, DRIVOUT.DAT, GAME.DAT, and SRUREPT.DAT. This appendix contains illustrations of fragments of those files. Except for DRIVOUT.DAT, the fragments include information relating to the third and fourth LRUs in a data set that has been processed by the suite of programs. In addition, a sixth file, called LSRUNAME.DAT, carries identifying information that is not needed by LSRU but is used by other DRIVE programs. The primary kinds of information dealt with by the various files are:

Input

- LSRUNAME.DAT: Identification of items and bases.
- LSRUMGT.DAT: Allowable LRUs missing and expected demands.
- LSRUDET.DAT: Item characteristics, depot assets, and base asset positions.

Output

- ITEMMGR.DAT: Distribution priorities.
- DRIVOUT.DAT: Repair priorities.
- GAME.DAT: Recording of LSRU's allocations for use by the DDSP.
- SRUREPT.DAT: Summary by LRU of sources and destinations for SRUs.

LSRUNAME.DAT

Figure C.1 contains a portion of LSRUNAME.DAT. The line below the date indicates that there are 34 LRUs and a total of 289 LRUs plus SRUs. Below that there is a line of three numbers for each LRU to help locate the LRUs in the main part of the file. The rightmost number is the sequence of the LRU, and the leftmost number shows where to find the information pertaining to the LRU in the main

```
15-FEB-90 -- Date from PPOUT.
  34 289   Number of LRUs,  Number of items.  Indices of LRUs and num SRUs
   1   9   1
  11   5   2
  17   5   3
  23   2   4
                                 ...
Line  L/S  TS  HOURS  NSN                      DESCR
                                 ...
  17  LRU  RF   24.4  1270-01-093-2256WF    RADAR XMTRHA3VP74ACO
  18  SRU   M   50.8  1270-01-083-0398WF    PRESS  VSLHA3VP74ACH
  19  SRU   A    7.8  1270-01-083-0473WF    POWER SPLYHA3VP74ACG
  20  SRU   M    5.1  1270-01-097-6096WF    DETECT ASYHA3VP74ACC
  21  SRU   D    6.6  1285-01-084-7356WF    DIGIBUS BDHA3VP74ACD
  22  SRU   A    8.7  5998-01-115-3249WF    BOARD ASSYHA3VP74ACB
  23  LRU  DI    6.3  1270-01-094-6872WF    RCP  74AHOHA5VV74AHO
  24  SRU   D    6.0  5985-01-072-6306WF    BOARD ASSYHA5VA74AHA
  25  SRU   D    7.1  5999-01-069-6483WF    BOARD ASSYHA5VA74AHD
                                 ...
      38  Number of Bases -- Organization, Base, Account
   1  419/388   HILL                 FB2027     TAC      1
   2  507TFG    TINKER               FB2037     TAC      1
   3  89TFS     WRIGHT PATTERSON     FB2300     ETC      3
                                 ...
```

Figure C.1—Partial Listing of LSRUNAME.DAT

body. The middle number is the number of distinct SRUs contained in the LRU. For example, the fifth line of the file contains the numbers 17, 5, and 3. This means that in the main part of the file, the description of the third LRU is on the line numbered 17, and that LRU has 5 SRUs.

The main body, following the header "Line L/S TS . . . ," contains the descriptions of the LRUs and SRUs. The TS column indicates the required test stands for LRUs and repair shops for SRUs. The next columns give standard repair hours and the national stock numbers. The description field contains four items: ten characters of nomenclature, three characters to indicate the item manager, two characters indicating the equipment specialist, and a five-character work unit code.

Below the item description lines in the main body is a section describing the bases. Each line indicates the unit, location of the base, the base supply account number, and the command to which the base belongs (a three-letter symbol and a DRIVE-peculiar numeric indicator).

LSRUMGT.DAT

The LSRUMGT.DAT file, illustrated in Figure C.2, is in three parts. The top line contains some control information and constants. Next is information about bases, followed by a block of data for each LRU.

Top Line

"PR LIM" is the probability stopping constant, and "SORT V LIMIT" is the sort value stopping constant. "AIS HRS" may be used to limit the amount of repair priority information written out by LSRU (i.e., stop when the total of LRU repair hours exceeds the value). The "CAR FLG" is the choice of how to regard carcass constraints, and "SRU OK PROB" is the specified probability of having enough SRUs to ensure LRU repairs will be successful. The three fields labeled "LGR" are weights that can be applied to hours for the SRU repair shops in computing the denominators of sort values. Finally, "A" and "B" are constants for the Sherbrooke regression used to compute variance-to-mean ratios.

Base Information

The only information used by the LSRU program is the horizon, which goes into the computation of VTMRs.

LRU Data

Each labeled panel is a folded vector, with one entry for each base. There are at most ten entries per line, and since there are 38 bases in this example, every panel has four lines. The first panel, "Authorized WRM," shows the number of LRUs that the bases are authorized to have in their WRSK. DRIVE does not use this information, but it is displayed by the DDSP (described in Section 5). The next panel, "Allowable LRU Removals," is the number of LRUs that the bases are allowed to have missing from aircraft at the end of their horizons. "Base DIFM" is the number of LRUs in base maintenance. The remaining data are the expected demands. The LRU comes first, followed by a panel for each of its SRUs.

LSRUDET.DAT

The LSRUDET.DAT file, illustrated in Figure C.3, is organized by LRU family, and within an LRU, there are three parts.

```
      0.95    38     2 99999  0.0005     0    0.90          1.00   1.00 1.00 0.14 0.50
        PR   NUM   CAR    AIS    SORT V PROD/ SRU OK          LGR   LGR  LGR    A    B
       LIM BASES FLG    HRS     LIMIT PLAN    PROB          ANA   DIG   MW     *V/M*

           NMC Total % Avl  Hor- Mth Fly     Base           Com-   Cmnd
    Base  Goal   A/C  Goal  izon Program     Name           mand   Code
      1     10    68    85    24    1424     HILL           TAC       1
      2      3    24    85    27     418     TINKER         TAC       1
      3      2    18    85    27     346     WRIGHT PAT     ETC       3
                                  ...
LRU   3 Authorized WRM
      10       10        0        0        0        0        0       14       15        5
       0        0        0        0        0        0        0        0        0        4
       0        4        0        0        0        0        4        1        0        1
       4        0        0        5        3        0        0        4
LRU   3 Allowable LRU removals
       3        4        3        0        0        0        0       10       11        0
       0        0        0        0        0        0        0        0        0        0
       0        3        0        0        0        0        1        0        0        0
       0        2        0        3        3        0        0        3
LRU   3 Base DIFM
       4        0        1        0        0        0        0       10        8        0
       0        0        0        0        0        0        0        0        0        0
       0        1        0        0        1        0        0        0        0        3
       2        0        0        3        3        0        0        0
Item   17  LRU   3  SRU  0 expected demands.
   5.417    5.674    3.812    0.110    0.346    0.000    0.129   15.922   17.439    0.157
   0.333    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.172
   0.214    4.277    1.124    0.210    4.208    0.503    1.355    4.288    0.000    4.073
   4.284    3.304    0.222    5.449    4.039    0.415    0.197    1.665
Item   18  LRU   3  SRU  1 expected demands.
   0.760    0.891    0.737    0.513    0.000    0.000    0.599    3.961    4.655    0.731
   1.552    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.799
   0.997    0.770    0.000    0.976    1.512    2.340    0.000    0.820    0.000    0.887
   0.799    0.487    1.036    0.910    0.724    0.000    0.916    0.307
                                  ...
Item   22  LRU   3  SRU  5 expected demands.
   0.068    0.080    0.066    0.046    0.000    0.000    0.054    0.355    0.417    0.065
   0.139    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.072
   0.089    0.069    0.000    0.087    0.135    0.233    0.000    0.073    0.000    0.079
   0.072    0.044    0.093    0.081    0.065    0.000    0.082    0.027
LRU   4 Authorized WRM
       2        2        0        0        0        0        0        5        3        3
                                            ...
```

Figure C.2—Partial Listing of LSRUMGT.DAT

```
L S T Q                         **** DEPOT ****                              BASES
R R S P    RPR      STD   SVC   UNS   UNS   NHA DIFO   MIC   EXP     STO HOL   L H H H
U U T A     PR      M/H   O/H   O/H    1R   AWP   AWP  SRV NRTS       CK  ES

                                                   . . .
3   3 1           24.40     0    36    13           0           23
3 1 2 1 1.000 50.80    11    32   107     0              11  106
3 2 0 1 0.020   7.80     3    10     0     0               1    1
3 3 2 1 0.260   5.10     0     4     1     0               0   18
3 4 1 1 0.050   6.60     5     0     3     0               3    1
3 5 0 1 0.050   8.70     0    56     1     0               2   10
3 0   11  0   7  0   3  0   0  0   1  0   0  0   5  0   7  0  15  0   7  0
3 1    4  0   2  0   1  0   0  0   0  0   0  0   0  0  16  0   1  0   5  0
3 2    1  0   1  0   0  0   0  0   0  0   0  0   0  0   2  0   1  0   1  0
3 3    0  6   1  0   1  0   0  0   0  0   0  0   0  0   1  1   1  0   1  2
3 4    0  0   1  0   0  0   0  0   0  0   0  0   1  0   2  0   0  0   0  0
3 5    1  0   0  0   0  0   0  0   0  0   0  0   1  0   0  0   3  0   1  0
3 0    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   5  0
3 1    3  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   1  0
3 2    0  0   0  0   0  0   0  0   0  0   0  0   1  0   0  0   0  0   0  0
3 3    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  1
3 4    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
3 5    2  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   1  0
3 0    3  0   5  0   3  0   5  0   3  0   3  0   1  0   3  0   0  0   2  0
3 1    6  0   0  0   1  0   0  0   3  0   1  0   2  0   0  0   0  0   1  0
3 2    0  0   0  0   0  0   0  0   0  0   0  0   0  0   2  0   0  0   2  0
3 3    1  1   1  0   0  0   0  1   1  0   1  0   1  0   0  0   0  0   0  0
3 4    0  0   1  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
3 5    2  0   2  0   0  0   0  1   0  0   2  0   0  0   0  0   0  0   1  0
3 0    5  0   0  0   3  0   8  0   1  0   0  0   5  0   2  0
3 1    1  0   1  0   1  0   7  0   2  0   0  0   3  0   1  0
3 2    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
3 3    1  0   0  0   0  0   1  0   1  0   0  0   0  0   0  0
3 4    0  0   0  0   0  0   1  0   0  0   0  0   0  0   0  0
3 5    1  0   0  0   1  0   1  0   1  0   0  0   0  0   0  0
4   1 0 0.100   6.30     4    46    12           3          31
4 1 1 1 0.210   6.00     0     1     0     2               0    0
4 2 1 1 0.140   7.10     0     0     1     1               0    0
4 0    8  0   4  0   0  0   2  0   1  0   0  0   2  0  10  0   5  0   2  0
4 1       0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
4 2    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
4 0    2  0   0  0   1  0   0  0   0  0   2  0   0  0   0  0   0  0   2  0
4 1    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
4 2    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
                                  . . .
4 2    0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
4 0 1
4 1 0
4 1 0
```

Figure C.3—Partial Listing of LSRUDET.DAT

Item and Depot Data

The column headings through "EXP NRTS" apply to the first part. The first two columns indicate the LRU and SRU (the SRU column is blank for the LRU). The next column, labeled "TST," specifies the repair resource: 0 through 3 for LRU test stand and 0 through 2 for SRU shop. (These are specific to Ogden.) "QPA," meaning quantity per application, is the number of LRUs in the aircraft or number of SRUs in the LRU. The column labeled "REP PR" is the replacement factor, defined as the probability that an SRU of this type will need replacement in an LRU repaired at the depot. Following, in the column labeled "STD M/H," are standard hours for repair. The next three columns are counts of depot assets. "SVC O/H" are serviceable items in depot stock, "UNS O/H" are repairable carcasses at the depot that have not been inducted, and "UNS IR" are items that have been inducted into the shops. "NHA AWP" for SRUs are numbers missing from LRUs in depot repair. "DIFO AWP" is a count of LRUs in depot repair that have been diagnosed and for which the SRUs needed to repair them are known. "MIC SRV" is the number of serviceable SRUs in the LRU shop available for installing in LRUs. The final column, "EXP NRTS," is the total expected number of items to be returned to the depot during the bases' horizons. This is not used by the prioritization procedure.

Base Asset Positions

The mass of numbers below the item and depot data are the bases' asset positions represented by stock and holes for each item at each base. The data is organized in the following way: for LRU 3, the first six entries in the column under the SRU heading are 0 through 5, representing the LRU and its five SRUs. Across the rows are ten pairs of columns for the first ten bases. The left column of a pair is the stock, and the right column is the holes for the item at the corresponding base. The whole pattern is repeated below for bases 11 through 20, and again for bases 21 through 30, and finally for the last 8 bases.

Diagnosed LRUs in Depot Repair

The number of LRUs in depot repair for which the needed SRUs are known is given in the "DIFO AWP" column in the first line of an LRU's package of data. For LRU 3 there are none, but LRU 4 has three. The last three lines of Figure C.3 indicate the condition of these LRUs. The two columns to the right of the fours correspond to

SRUs and tell how many SRUs are missing. Thus, the first LRU is waiting for SRU 2, and the other two LRUs are both waiting for SRU 1.

ITEMMGR.DAT

The ITEMMGR.DAT file, shown in Figure C.4, is used to generate the distribution recommendations. One or more lines are written to the file each time the prioritization procedure makes a repair/distribution choice. The first two columns, labeled "L" and "S," indicate the LRU and SRU. A zero in the SRU column indicates the LRU. The third column, headed by "B," designates the base to receive the item. SRUs intended for the LRU shop have destinations equal to 0. The column labeled "SV" contains the sort values associated with the choice. These are used later to merge into single lists the distribution recommendations for SRUs that are used in more than one LRU. The column labeled "Xctn" is the transaction number associated with the prioritization procedure's choice. Every time a repair/allocation decision is made, a counter is bumped and associated with the choice. Primarily a debugging tool, transaction numbers allow the various outputs to be related. The last column, labeled "K," reports the kind of transaction. The coding is 0 = from depot stock, 1 = induction of either an LRU or an SRU, and 2 = complete the repair of an AWP LRU. Notice that transaction number 197 appears on two successive lines. The first line shows that an LRU is to be inducted for base 32, and the next line specifies that a type 3 SRU is to be repaired and sent to the LRU shop.

DRIVOUT.DAT

The DRIVOUT.DAT file, shown in Figure C.5, is used to produce repair priority lists. The information in this file relates only to repair actions; allocations from depot stock are not indicated. The first four columns are, respectively, the sort value, transaction number, identification of the LRU involved, and the base for which the repairs indicated by the rest of the line are being done. The remaining columns, numbered 0, 1, . . . are cumulative numbers of repairs for the LRU and constituent SRUs. The lines are of varying length because of differing numbers of SRUs. The first four lines in the partial listing call for repairs of LRU 23, and they are the 40th through the 43rd LRUs of that type on the list. Comparing the first two lines (transactions 2368 and 2369), we see that SRUs numbered 6, 7, 9, and 10 should also be repaired along with the 41st LRU. The 13th line

L	S	B	SV	Xctn	K
			...		
3	3	11	0.03672	187	1
3	1	30	0.03663	188	0
3	1	11	0.03037	189	0
3	1	26	0.02983	190	0
3	3	4	0.01406	191	1
3	2	11	0.01038	192	0
3	3	28	0.00697	193	1
3	3	11	0.00681	194	1
3	3	32	0.00534	195	1
3	5	4	0.00465	196	1
3	0	32	0.00390	197	1
3	3	0	0.00390	197	1
3	4	11	0.00387	198	0
3	2	4	0.00386	199	0
3	0	28	0.00351	200	1
3	0	36	0.00334	201	1
3	3	0	0.00334	201	1
3	0	11	0.00320	202	1
3	5	25	0.00277	203	1
3	0	32	0.00244	204	1
3	3	0	0.00244	204	1
3	0	28	0.00237	205	1
3	0	25	0.00237	206	1
3	0	28	0.00161	207	1
3	3	0	0.00161	207	1
3	0	25	0.00161	208	1
			...		

Figure C.4—Partial Listing of ITEMMGR.DAT

(transaction 770, involving LRU 11) must be calling for the repair of the fourth SRU in that LRU since the cumulative numbers for everything else in the line are 0.

GAME.DAT

The GAME.DAT file is used by the DRIVE Decision Support Program (DDSP). As described in Section 5, the DDSP is an interactive program that replays the actions of the prioritization algorithm one step

Sort Valu	Xctn	LRU	Base	0	1	2	3	4	5	6	7	8	9	10	11	12
						...										
1.6167160	2368	23	27	40	6	0	4	16	2	5	12	3	6	88	0	3
1.6147160	2369	23	8	41	6	0	4	16	2	6	13	3	7	89	0	3
1.6143650	2370	23	22	42	6	0	5	16	2	6	13	3	7	90	0	3
1.6137950	2371	23	9	43	6	0	5	17	2	6	13	3	7	91	0	3
0.4324628	1045	13	28	1	0	1										
0.2238749	90	2	11	0	0	0	1	0	0							
0.2077599	235	4	32	1	1	0										
0.2072761	187	3	11	0	0	0	1	0	0							
0.1877272	2769	27	27	1												
0.1802041	720	10	28	0	1	0	0	0	0	0	0	0	0	0	0	0
0.1726287	2030	21	25	1	0	0										
0.1323896	842	12	25	1	0	2	0	0	0	0	0	0	0	0	0	
0.1216177	770	11	31	0	0	0	0	1	0							
0.1173946	2571	25	30	1	0	0	0	0	0	0	1	0	0	0	0	0
0.1090784	1696	18	25	1	1	0	0									
0.1080594	545	8	11	8	0	0	2	0	4	0	8	1				
0.0941031	2938	30	7	2												
0.0914386	2939	30	25	3												
0.0907579	2678	26	25	0	0	0	0	0	0	0	0	0	0	0	0	0
0.0893380	1893	20	31	0	0	0	0	0	0	0	0	0	0	1	0	
0.0863034	375	6	11	4	0	0	1	0	2	0	4	1				
0.0860987	2940	30	31	4												
0.0782478	1307	16	31	0	0	0	0	0	0	0	0	0	1	0	0	0
0.0762689	1763	19	25	1	0	0	0	1	0	0						
0.0703370	1309	16	2	0	0	0	0	0	0	0	0	0	1	0	0	0
0.0570915	2	1	25	1	0	0	0	0	0	0	0	0	0			
0.0535748	2822	29	31	1	0	0	0	0	0							
0.0519372	3115	31	27	1	0	0	0	0	1	0	0	0	0	0		
0.0518103	3267	34	25	1												
						...										

Figure C.5—Partial Listing of DRIVOUT.DAT

at a time and provides a great deal of information about the evolving status of the depot and bases if the recommendations of DRIVE were to be carried out exactly. A line is written to the file for every item that the LSRU program decides to ship to a base. The sample in Figure C.6 is the beginning of a sequence for LRU 3 in a sample run of LSRU.

The first line identifies the start of transactions for the LRU. In the second line, the first four fields are meaningless placeholders. The fifth position is the overall probability of meeting all the bases' proba-

```
        X   L   S   B       H    Prob    BP K   F    SV
                               ...
        0   3   0   0    0.0 0.0000 0.00 0   0 0.00000 HEADER FOR START OF
NEW LRU
        0   3   0   0 0.0024 0.98 0.92 0.88 0.51 0.94 1.00 1.00 0.94 0.94
      179   3   1   4    0.0 0.0032 0.71 0   0 0.31544
      180   3   1  28    0.0 0.0038 0.39 0   0 0.16169
      181   3   1  26    0.0 0.0042 0.87 0   0 0.09290
      182   3   1   4    0.0 0.0045 0.77 0   0 0.08401
      183   3   1  11    0.0 0.0048 0.55 0   0 0.06342
      184   3   1  28    0.0 0.0051 0.42 0   0 0.06116
      185   3   1  26    0.0 0.0054 0.92 0   0 0.05301
      186   3   1  32    0.0 0.0056 0.43 0   0 0.03822
      187   3   3  11    5.1 0.0068 0.66 1   0 0.03672
      188   3   1  30    0.0 0.0070 0.70 0   0 0.03663
      189   3   1  11    0.0 0.0072 0.68 0   0 0.03037
      190   3   1  26    0.0 0.0075 0.95 0   0 0.02983
      191   3   3   4    5.1 0.0080 0.82 1   0 0.01406
      192   3   2  11    0.0 0.0081 0.69 0   0 0.01038
      193   3   3  28    5.1 0.0084 0.43 1   0 0.00697
      194   3   3  11    5.1 0.0087 0.72 1   0 0.00681
      195   3   3  32    5.1 0.0089 0.44 1   0 0.00534
      196   3   5   4    8.7 0.0093 0.86 1   0 0.00465
      197   3   0  32   77.4 0.0126 0.59 1   0 0.00390
      198   3   4  11    0.0 0.0126 0.72 0   0 0.00387
      199   3   2   4    0.0 0.0127 0.86 0   0 0.00386
      200   3   0  28   77.4 0.0166 0.57 1   0 0.00351
      201   3   0  36   77.4 0.0215 0.91 1   0 0.00334
      202   3   0  11   77.4 0.0276 0.92 1   0 0.00320
      203   3   5  25    8.7 0.0282 0.57 1   0 0.00277
      204   3   0  32   77.4 0.0341 0.72 1   0 0.00244
      205   3   0  28   77.4 0.0410 0.68 1   0 0.00237
      206   3   0  25   77.4 0.0492 0.69 1   0 0.00237
      207   3   0  28   77.4 0.0558 0.78 1   0 0.00161
      208   3   0  25   77.4 0.0632 0.78 1   0 0.00161
   ...
```

Figure C.6—Partial Listing of GAME.DAT

bility goals before any items are allocated. Following that are the individual bases' starting probabilities. (There are 38 in the example; the line is truncated in the figure.) The labels at the top of the figure pertain to the remaining lines.

The first four columns indicate the following: "X" is the transaction number, "L" is the LRU family, "S" is the SRU sent to the base, and "B" is the base to receive the item. Next, "H" is the repair hours, which are zero for issues from depot stock. The column labeled "Prob" is the overall probability for the LRU achieved thus far, and the column marked with "BP" is the probability for the base to which the item is sent. "K" is the kind of transaction (0 = ship from stock, 1

= induct and repair, 2 = finish the repair of an AWP LRU). "F," for finish, indicates which of the AWP LRUs is to be the one completed. The last column contains the sort values.

SRUREPT.DAT

The SRUREPT.DAT, in Figure C.7, is mainly for debugging, but users have claimed it to be of value. Information is written to the file after the LSRU program finishes with each LRU. The top part shows how many AWP LRUs were finished and available, and it shows how many LRUs were inducted and how many carcasses were on hand. We also see the condition that caused the LSRU program to terminate processing of the LRU family. For LRU 3 in the example, the stopping condition was reaching the specified sort-value threshold. For LRU 4, the supply of SRU carcasses that could be repaired in order to finish AWP LRUs ran out before the sort value or probability limits were reached.

The rest of the display for an LRU family concerns the SRUs. The three lines show the depot replacement factors, expected number of SRUs needed for the LRU inductions specified, and the expected number plus two standard deviations. The next three lines show how SRUs were utilized: either sent to the LRU shop for inducted LRUs, used for finishing AWP LRUs, or sent to bases. The next three lines give an accounting of the sources of the LRUs: MIC stock, normal depot stock, and repair. The bottom line tells how many SRU carcasses were available. If there are repairs of an SRU, the sum going to the three destinations should equal the sum over the three sources. In the case of SRU 4 in LRU 3, of the eight serviceable SRUs, only six were utilized.

```
 LRU  3   Number Finished =   0   Number inducted =  30  Prob = 0.27751
          Number AWP LRUs =   0         Carcasses =  49  S.V. = 0.00050
          Ended by reaching low sort value
SRU             1    2    3    4    5
Rplcmnt Fctr  1.00 0.02 0.26 0.05 0.05
E(# SRUs)     29.7  0.6  7.8  1.5  1.5
E + 2 * sd    30.8  2.1 12.6  3.9  3.9
              -------------------------
For Ind LRUs  30    2   12    5    4
For Fin LRUs   0    0    0    0    0
To Bases      11    2    5    1    2
              -------------------------
Init MIC Stk  11    1    0    3    2
Init D Stock  11    3    0    5    0
num To Repar  19    0   17    0    4
              -------------------------
Carcasses     139   10    5    3   57


 LRU  4   Number Finished =   2   Number inducted =  58  Prob = 0.86588
          Number AWP LRUs =   3         Carcasses =  58  S.V. = 0.00000
          Ended by running out of carcasses
SRU             1    2
Rplcmnt Fctr  0.21 0.14
E(# SRUs)     12.2  8.1
E + 2 * sd    18.4 13.4
              ----------
For Ind LRUs  17   13
For Fin LRUs   1    1
To Bases       0    0
              ----------
Init MIC Stk   0    0
Init D Stock   0    0
num To Repar  18   14
              ----------
Carcasses     18   14
```

Figure C.7—Partial Listing of SRUREPT.DAT

BIBLIOGRAPHY

Abell, John B., Louis W. Miller, Curtis E. Neumann, and Judith E. Payne, *DRIVE (Distribution and Repair in Variable Environments): Enhancing the Responsiveness of Depot Repair*, RAND, R-3888-AF, 1992.

Crawford, Gordon B., *Variability in the Demands for Aircraft Spare Parts: Its Magnitude and Implications*, RAND, R-3318-AF, January 1988.

Culosi, Salvatore J., *An Analysis of Issues Related to Implementing the DRIVE Model*, Logistics Management Institute, Report AF002R1, April 1991.

Hodges, James S., *Modeling the Demand for Spare Parts: Estimating the Variance-to-Mean Ratio and Other Issues*, RAND, N-2086-AF, May 1985.

O'Malley, T. J., *The Aircraft Availability Model: Conceptual Framework and Mathematics*, Logistics Management Institute, Bethesda, Md., June 1983.

Sherbrooke, Craig C., *Estimation of the Variance-to-Mean Ratio for AFLC Recoverable Items*, Sherbrooke and Associates, Potomac, Md., January 27, 1984.